The AMERICAN PHYSICS TEACHER

VOLUME 5 | APRIL, 1937 | NUMBER 2

The Physical Content of Quantum Mechanics

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THE physical ideas involved in the system of thought and calculation known as "quantum mechanics" have developed to a considerable extent after the development of the mathematical methods. This is contrary to what might be thought to be the correct method of developing physical theory, namely to have a clear physical idea and then express it in mathematical language. On the other hand, it must be realized that the development of new concepts is much more difficult than the mathematical elaboration of old ones, and it need not be surprising that the development has been halting.

That there is at present no unanimity as to the physical content of quantum mechanics is evidenced by the number of papers which have recently appeared commenting on the treatment by Einstein, Rosen and Podolsky[1] of an apparent paradox in the quantum-mechanical treatment. These papers have presented a surprising number of different attitudes toward the subject. I shall attempt to give here, in very elementary form, an attitude toward quantum mechanics which is self consistent and which I believe approximates very closely to that of Bohr[2] and others.

Classical and quantum-mechanical prediction

The object of a physical theory is to predict from a certain set of experiments the results of other experiments or measurements to be performed in the future. In classical mechanics the behavior of a system is predicted by

(*a*) measuring the coordinates and velocities, or momenta, of the system at some time $t=t_0$; and

(*b*) using the laws of motion, that is, Newton's, Lagrange's, or Hamilton's equations, to predict the future values of these coordinates and momenta. The knowledge of the physical nature of the system is included in the form of these equations. This is really a prediction of the results of future experiments, since it is presumed that the future values will be measured in some way.

Both parts of this process are essential. Without some initial conditions the solutions of the equations of motion give no specific results; and without the use of the laws of motion, a single observation of the system is of little use. It may be mentioned here that in finding the initial conditions it is the values of the coordinates and momenta after the determination is made which are desired. In classical theory, it is assumed that the various quantities can, in principle, be measured without interfering with them; but in case such methods are used as do interfere, it is certainly the values after the measurement which are inserted as initial conditions in the solutions of the differential equations.

The procedure in quantum mechanics is very analogous to that of classical theory. The "state of the system" is

(*a*) determined at some definite time $t=t_0$; and then

(*b*) predicted for some future time by means of the equation of motion, namely, the Schroedinger equation.

[1] Phys. Rev. **47**, 777 (1935).
[2] Phys. Rev. **48**, 696 (1935).

The state of the system can be represented in various ways. A familiar way is by means of the Schroedinger wave function $\psi(q, t)$ which is a function of the coordinates and the time. The determination of the state of the system is made by making measurements of certain quantities in ways which will be discussed in more detail later. When the state is determined at some initial time, it can then be known at any later time—as long as the system is kept isolated—by means of the equation

$$-(h/2\pi i)(\partial\psi/\partial t)=H\psi, \qquad (1)$$

where H is a differential operator which corresponds to the Hamiltonian function of the system in question. This equation governs the change of the state as long as it is isolated; but the development of the quantum mechanics has emphasized the fact that an isolated system cannot be observed, that an observation is an interference with the system, and hence that predictions can be made only as far ahead as the first observation after the one which fixes the initial state.

Thus in either classical or quantum mechanics, a significant experiment can be performed by making an observation at $t=t_0$, predicting the result of an experiment at $t=t_1$, and checking this prediction at t_1. In the classical theory the prediction of any physical quantity is exact, provided an adequate determination of the initial conditions is made. In the quantum theory also some predictions are exact, but the normal case is that only a prediction of probability can be made. The wave function can always be exactly predicted, but the connection of this with the results of observations is usually statistical.

Interpretation of the state of a system

In case the state of the system at the time t is known it is possible to determine from it the probability of any result of an experiment. Consider the state to be described by the wave function $\psi(q, t)$, and suppose the experiment is designed to measure the quantity R. The rule is then to take the operator $\mathbf{R}$ which "corresponds to R" and to evaluate the integrals

$$\overline{R^n}(t)=\int\psi^*(q, t)\mathbf{R}^n\psi(q, t)dq \qquad (2)$$

for all different values of n. These give the average, or expectation, values of the corresponding powers of R. A knowledge of all of these is equivalent to a knowledge of the distribution of R, or of the probability of any value of R, in that the probability of any value of R can be determined from these average values. If, for example, the average of the nth power of R is equal to the nth power of the average for all values of n, there is no spread at all in the possible values and the quantity is specified exactly by the function. If the average of all of the odd powers is zero, the probability of a certain positive value is equal to the probability of the same negative value.

The question arises as to whether there is an operator "corresponding" to every physical quantity. A physical quantity can be defined by the means used to measure it, and so the operator corresponds perhaps more to the particular operations involved in the experiment than to anything having a more abstract existence. Apparently this question has not been given a complete answer, but in any case the determination of the proper operator is a matter more for experiment than for analysis.

Certain operators are well known. When the $\psi(q, t)$ functions are expressed in Cartesian coordinates, the operator which corresponds to an experiment which, interpreted classically, measures the momentum of a particle in the x direction, is $(h/2\pi i)(\partial/\partial x)$, the operator for angular momentum about the z axis is $(h/2\pi i)(x(\partial/\partial y)-y(\partial/\partial x))$, the operator for the x coordinate is simply multiplication by x, etc. For functions of these quantities, the operator is usually the corresponding function of the component operators, but because the operators do not always commute with each other, this function of the operators is not always uniquely defined. In case there are several possible functions which satisfy the mathematical conditions for physically significant operators, and which differ only because the operators do not commute, these may be considered to represent physical quantities that strictly are different, but that coincide in the limit in which classical mechanics is valid.

Another question is as to whether there corresponds a possible physical quantity, or experimental operation, to every mathematically

suitable operator. This question has apparently not been given a general answer.

As an example of the interpretation of the state of a system consider a particle which can move in one dimension only, and let its coordinate be x. Then suppose that at the time t_0, the particle is known to be in the state described by the Schroedinger function

$$\psi(x, t_0) = Ae^{-\alpha x^2/2}. \tag{3}$$

How this knowledge can be acquired will be discussed later. This is a complete description of the system at the time t_0 and contains all that can be known about it. One may ask, for instance, for the value of the coordinate, that is, the position of the particle. The answer is that the coordinate is indeterminate, that the coordinate is not a well-defined characteristic of the particle in this state. Nevertheless an average value for the coordinate can be obtained from the integral

$$\bar{x} = |A|^2 \int_{-\infty}^{\infty} xe^{-\alpha x^2} dx = 0.$$

This means that if an experiment is performed to determine the value of the coordinate x, and is performed a great many times on different systems all of which are known to be in the state represented by $\psi(x, t_0)$, the average of the results obtained will be zero. Similarly the average of any odd power will be zero while the averages of the even powers will be different from zero. The knowledge of the averages of all of the powers is equivalent to the knowledge of the probabilities of all the values.

Furthermore, in the state represented by Eq. (3) the momentum of the particle is also indeterminate but the wave function gives some information about the result of an experiment to measure it. The average value of the momentum in the x direction, in the sense just described for the coordinate, is given by

$$\bar{p} = \frac{h}{2\pi i} |A|^2 \int_{-\infty}^{\infty} e^{-\alpha x^2/2} \frac{\partial}{\partial x} (e^{-\alpha x^2/2}) dx = 0.$$

This implies that the probability of finding the momentum in one direction is the same as that of finding it in the other. The averages of other powers of the momentum can be found from similar integrals. For this particular wave function it is possible to show that the probability of finding a momentum between p and $p+dp$ is just given by the function

$$\frac{2\pi}{\alpha h} |A|^2 e^{(-4\pi^2/\alpha h^2)p^2} dp.$$

It is possible to show quite generally that with this method of determining probabilities from a wave function there results the inequality

$$(\overline{x^2} - \bar{x}^2)(\overline{p^2} - \bar{p}^2) \geqslant h^2/16\pi^2. \tag{4}$$

For the particular wave function used here as an example, the equality sign holds; but for functions in general the inequality is applicable. This is Heisenberg's principle of indetermination. It can be regarded as a direct consequence of the use of a wave function and the methods used for interpreting it, so that whatever physical significance is ascribed to this principle must be regarded as equivalent to the physical significance of the wave function itself.

The principle of indetermination has been illustrated with the coordinate and the conjugate momentum. It applies, however, to every pair of canonically conjugate quantities. The derivation depends only upon the fact that the operators for the two quantities are connected by the commutation rule

$$\mathbf{PQ} - \mathbf{QP} = (h/2\pi i)\mathbf{1}. \tag{5}$$

In the case of the example given, the quantities x and p were indeterminate and the predictions made about experiments to measure them could be statistical only. However, the knowledge of the state is very definite and not all quantities are indeterminate. The quantity $[p^2 + (\alpha^2 h^2/\pi^2)x^2]$ has the definite value $\alpha h/2\pi^2$, and any function of this quantity has a precisely known value. The state is characteristic of this quantity $[p^2 + (\alpha^2 h^2/\pi^2)x^2]$ and the Schroedinger function $Ae^{-\alpha x^2/2}$ is a characteristic function or eigenfunction with the eigenvalue $\alpha h^2/2\pi^2$.

Determination of the state of a system

Without a knowledge of the state of the system at some time t_0 it is impossible to make any precise predictions about its state at a future

time, and so some attention should be given to the kinds of experiments which can be used for determining the initial state. The way in which the question is put implies an attitude toward the answer. One might ask, "How can the state of the system at the time t_0 be discovered?" This would imply the existence of the system in a definite state and the use of an experiment to determine what the state is. On the other hand, one might ask, "How can the state of the system be prescribed?" The latter question would imply that only the state of the system after the experiment is of importance, and would ignore the state before the experiment. It implies that if the experiment changes the state of the system, this change is to be taken into account, and that the experiment is really a preparation of the system in a given state. Only this latter attitude can be consistently maintained in quantum mechanics. Let us then consider a few examples of the prescription of a state at the time t_0.

1. As a first example consider the famous "gamma-ray microscope." This is a classically customary method of locating a particle by looking at it or photographing it. The particle is illuminated by light of which some is scattered through the lens to form an image on the plate at P, Fig. 1. If only a single photon is scattered, the time at which it was scattered can be inferred from the time at which it strikes the plate. More than one scattered photon cannot be used, for in general the particle would move between the impacts of one photon and the next, so that only the last would give a suitable measure of its position. But since one photon will form only one spot on the plate it is necessary to use light of very short wave-length, so that one spot will effectively coincide with the center of the interference pattern which would have been formed had many photons been scattered from this same point. In the limit, when light of infinitely short wave-length is used, the position of the particle, relative to the microscope and the framework to which it is attached, can be determined with any desired precision.[3] This position measurement will then be an "initial condition" for the future

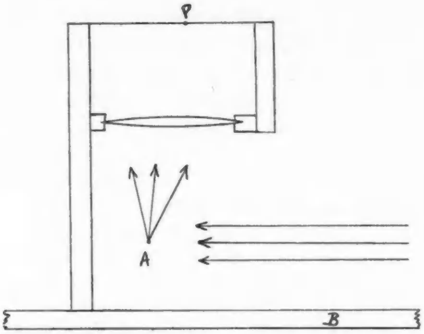

FIG. 1. The gamma-ray microscope. The lens and the plate are rigidly fastened to the base B which serves to define the coordinate system. A position P on the plate can therefore be interpreted as a coordinate measurement without any uncertainty.

motion of the particle, and the wave function which is ascribed to the particle must be such that it represents the particle at the observed point at the time t_0. This function can differ from zero only at the point r_0 and will be[4]

$$\psi(r, t) = \{\delta(r - r_0)\}^{\frac{1}{2}}. \tag{6}$$

This state will then change in accordance with the Schroedinger equation and will give the subsequent behavior of the particle.

2. Another type of experiment gives a state in which the momentum is defined and the wave function is that of a plane wave. Let a beam of particles be incident on a grating through a set of slits which will define the angle of incidence. If, then, a particle is scattered so as to pass through a set of slits defining a definite angle of diffraction, the wave function which represents the state will be that for a plane wave. The wave-length will be connected with the momentum of the particle by the de Broglie relationship $\lambda = h/p$, so that

$$\psi(x, t_0) = Ae^{2\pi i(p/h)x}, \tag{7}$$

where x is measured along the direction defined by the slits through which the particle is scattered. Of course this simple plane wave function is a limit which is approached as the grating and the slits are made larger so that the resolving power increases and the wave-length is more sharply defined. For this reason the position of the particle is entirely undetermined by the

[3] Since we are dealing with nonrelativistic quantum mechanics only, the finiteness of c is ignored and h/mc is treated as zero. Hence the uncertainty which is introduced because the wave-length after scattering is at least h/mc is neglected.

[4] This δ function is defined by the fact that it is zero when $r \neq r_0$, and $\int \delta(r - r_0)dv = 1$. It may be pictured as the limit of a set of functions $\lim_{\alpha \to \infty} (\alpha/\pi)^{3/4} e^{-\alpha\{(x-x_0)^2+(y-y_0)^2+(z-z_0)^2\}}$.

experiment. This type of experiment is the antithesis of the gamma-ray microscope since the very property which makes possible an accurate determination of λ and p entirely precludes any knowledge of the position of the particle under consideration.

These two types of experiment are commonly known in quantum mechanics since they correspond to the classical determination of position and momentum. There are, however, others which can be used.

3. The angular momentum of an atom can be prescribed by sending a beam through an inhomogeneous magnetic field. By means of slits the atoms having different components of angular momentum in the direction of the field can be separated and their future behavior observed. This corresponds to a determination of only one factor in the wave function since the wave function requires for its unique determination the specification of as many quantities as there are degrees of freedom.

4. If it is desired to produce a particle in the state described by the function $\psi(r, t_0) = Ae^{-r^2/2a^2}$, it can be connected to the origin by some elastic device such as a spring with a suitable force constant and a vanishingly small viscosity. In the case of a charged particle the viscosity is unnecessary since the necessary damping is produced by radiation. After a long time the particle will be known to be in the state of lowest energy because of the dissipation of energy in the viscous spring or in radiation. It will then be in the desired state, and if the connection with the origin is quickly broken the state will start to change according to the equation of motion for a free particle.

In all of these experiments there is an exact determination of some quantity, and in quantum mechanics as well as in classical mechanics this represents an idealization. A crude determination will not fix the state exactly. If the position of a particle is determined by using light of a finite wave-length in a microscope, or by allowing the particle to pass through a slit of finite width, the position will be determined within certain limits, and it will be known that the absolute value of the function differs from zero only within these limits. There is an infinity of functions, however, which satisfy this condition, since any originally chosen function can be multiplied by an arbitrary function of absolute value one without affecting its representation of this approximate knowledge of position. In particular there can be a δ function at every point within the allowed region, and these can be added together with various phase factors to give a suitable wave function. The state of the particle is thus not determined by this kind of an experiment. It is customary to describe this situation by saying that the system is in a "mixed state." This term is not very descriptive; it means that the state of the system is not precisely known, that it might be any one of a large number or an infinity of states which satisfy the conditions of the experiment, and that predictions as to the future state of the system can be made only in the sense of ordinary statistical mechanics.

Physical aspects of principle of indetermination

It has already been indicated that the principle of indetermination is a necessary concomitant of the description of the state of a system by means of a wave function and the prescribed methods of interpreting it. Nevertheless the question naturally arises as to whether this description is complete; as to whether the wave function gives everything about the system which has any physical significance. The question is sometimes put as to whether a particle does not *really have* both a definite coordinate and conjugate momentum which are, however, only inaccurately known. To some persons this latter form of question seems to have a definite meaning, but it is not easy to make it precise. One possible point of view is that it should be possible to make such experiments that the position and the momentum of a particle could both be determined accurately, and that the failure to find such experiments is due merely to lack of insight or ingenuity.

In contradiction to this attitude, Bohr has maintained that canonically conjugate quantities are, in their very concepts and definitions, complementary to each other and mutually exclusive. A position, for example, must be determined by reference to some coordinate system, which must in fact be a heavy material body. Momentum is defined essentially by its conservation law.[5] If now the position of a particle is to be determined, the particle must come in contact, perhaps indirectly, with the coordinate system. In this interaction momentum will be conserved, but it is necessarily impossible to know how much momentum has been transferred to the coordinate system. Any attempt to determine

[5] See E. Mach, *Science of Mechanics*, p. 238, for a discussion of the conceptual basis of Newtonian mechanics.

this quantity involves treating the coordinate system as a free body and referring it to another coordinate system, so that the usefulness of the first as an ultimate reference system is destroyed. On this account any measurement of position will destroy the value of a previous measurement of momentum.

Let us consider more in detail the gamma-ray microscope. Let us suppose that the momentum of the particle has been previously measured and is known to be p_0, and that the microscope is to be used to determine the position so that both quantities will then be known. The incident light may be taken to have a definite direction and wave-length, and hence each quantum will have a definite momentum which may be called p_1. In the interaction between the particle and the light quantum which is scattered there will be conservation of momentum, and the change of the momentum of the particle would be known if the final momentum of the quantum could be determined. However, in order that an observation can be made of the position of the particle the quantum must be allowed to pass undisturbed through the lens to impinge on the plate. The exact direction of the scattered quantum cannot be determined, for any reduction in the aperture of the lens would reduce the resolving power and hence the accuracy of the position determination. Thus the momentum of the scattered quantum cannot be determined before it is absorbed in the microscope. In addition the momentum given to the microscope by the light quantum cannot be determined, or even considered, for the microscope is necessarily rigidly fastened to the coordinate system and hence, by definition, cannot take on any motion. The very property of rigidity which makes it suitable for a position measurement entirely precludes the possibility of taking any account of the transfer of momentum from the particle to the microscope. A more detailed analysis of the operation of this particular instrument shows that the disturbance of the momentum of the particle can be reduced by the use of light of finite wave-length at the cost of precision in the determination of position, and that the relation between the maximum precision obtained in the position measurement and the minimum disturbance of the momentum is that given by the indetermination relation. Thus Bohr's contention is that position and momentum are, in their very definitions, quantities which cannot be precisely defined at the same time.

Another possible point of view might be that it is possible to imagine a classical description of the state of a particle, that is, a precise position and momentum, even though it is in principle impossible to determine them. It is, however, very difficult to give precision to such an idea. If it is admitted that a classical description of a state is really unattainable because of incompatibility in the definitions involved, the idea that such a state nevertheless exists is rather unsatisfactory.

A consistent point of view is that classical quantities exist only for limiting cases of quantum-mechanically defined states; and that canonically conjugate quantities are complementary in the sense that they cannot exist at the same time, as they characterize different limiting quantum-mechanical states which can be produced by suitable but mutually exclusive experiments.

Observation and causality in the quantum mechanics

The principle of indetermination has led to a good deal of discussion of the disappearance of causality from the world of science. Much of this discussion has been without any very adequate definition of what is meant by causality. It is true that classical mechanics permits a physicist to predict the behavior of an isolated system if its initial state is known, but quantum mechanics permits the same thing. In fact, without an equation describing the time behavior of the system there could be no mechanics at all. The difference lies in the idea of what constitutes a complete description of the state, and the emphasis placed on the fact that a really isolated system cannot be observed at all when quantities of the order of h are to be considered.

The quantum mechanics emphasizes the distinction between two different kinds of interactions. One is the ordinary interaction between the parts of the system under consideration, and the other is the interaction with a measuring instrument. It is only the latter kind of interaction to which the principle of indetermination

applies. The ordinary interaction between parts of a system goes on in a perfectly causal (although not necessarily classical) way according to the Schroedinger equation. The interaction with a measuring instrument, however, must be described in classical terms, and can be predicted in a statistical way only.

In making an observation there is usually a chain of interactions involved. Any one of these may be taken as the dividing line between the system and the measuring instrument. In the example of the gamma-ray microscope one may say that the microscope measures the position of the particle. Then the state of the particle, just after the interaction, is known; its position is exactly known although its momentum is entirely indeterminate, and the action of the microscope is described classically. In particular, the subsequent determination of the position of the spot on the plate in terms of the coordinate system and the perception of this result by the physicist is supposed to be entirely classical. On the other hand, the microscope may be considered as part of the system and the observation can be made on the microscope itself. This is a different selection of the interaction which is to be taken as dividing the system from the observer. In this case the microscope could not be fastened to the coordinate system, but must be free to move in its interaction with the particle. The position of the spot on the plate must then be measured with reference to the fixed coordinate system and the principle of indetermination will apply to this measurement. This change in the interaction which is considered as the observation does not carry with it any loss of choice on the part of the observer as to what is to be measured. When the particle alone is considered as the system its momentum could be measured instead of its position. The same thing is true when the microscope is part of the system, for the momentum of the microscope could be measured instead of its position. This measurement would entirely preclude a measurement of position, but because of the conservation of momentum in the interaction between the particle and the microscope, the measurement of the momentum of the microscope would serve to measure the momentum of the particle. The interaction to which the principle of indetermination is applied can be arbitrarily chosen, but it must always be included at some point in the chain between the system of interest and the observing physicist.

The necessity of clearly distinguishing between the observer and the things observed is common to all science. In the classical mechanics it is often overlooked because all interactions are treated in the same way. The quantum mechanics has emphasized this distinction by treating the interaction with the observer in this peculiar fashion, and by bringing to light the paradoxes which appear when this distinction is not carefully made.

One may say, then, that according to quantum mechanics, processes in the outside world go on in a perfectly causal way in that the state of a system changes in accordance with the Schroedinger equation. This does not mean that the processes go on in a classical fashion or can be at all classically described. It merely means that the development of the state of the system can be described by the Schroedinger equation as long as the system is isolated. As soon, however, as the observer interferes with the system, the causal development of the state is broken off and the interaction with the observer can be described only in terms of probabilities.

Criteria of Consistency and Concepts of the Dielectric Constant

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THE natures of the dielectric constant ϵ and the magnetic constant μ have recently formed the subjects of three excellent papers. One paper, that by Webster,[1] is limited to the discussion of the dielectric constant. The other papers, those by Page and Adams[2] and by Birge[3] include the subject of main interest here as parts of larger wholes. The last named paper is particularly comprehensive and thoroughgoing, and contains an excellent bibliography.

Webster has found it desirable to split the dielectric constant of a medium into two factors j and k in accord with the equation

$$\epsilon = k/j, \tag{1}$$

where k, the specific inductive capacity, is a pure number and hence dimensionless and where j, the constant of electrostatics, a quantity exactly analogous to the constant of gravitation, carries the dimensions of ϵ, if dimensions there are. By virtue of the definition of the unit electric charge, j may be evaluated precisely:[4]

$$j = 1(\text{dyne}\cdot\text{cm}^2/(\text{escoulomb})^2). \tag{2}$$

Webster has further concluded that it is a matter of convenience whether the dependency of the electric displacement D upon the field strength E and the dielectric polarization P is expressed in either the one or the other of two forms,

$$D_3 = kE = E + 4\pi jP \tag{3}$$

or[5]

$$D_4 = \epsilon E = \epsilon_0 E + 4\pi P. \tag{4}$$

Page and Adams[6] as their conclusion propose that we "define dielectric constant as the ratio of D to E when both are expressed in e.s.u., or in gaussian units, or in Heaviside-Lorentz units, and recognize that in e.m.u. the ratio of D to E is not the dielectric constant but the dielectric constant divided by c^2."

[1] Webster, Am. Phys. Teacher **2**, 149 (1934).
[2] Page and Adams, Am. Phys. Teacher **3**, 51 (1935).
[3] Birge, Am. Phys. Teacher **3**, 171 (1935).
[4] Webster has used *statcoulomb* where we use *escoulomb*.
[5] We prefer here to use ϵ_0 to replace the factor $1/j$ used by Webster. The subscripts 3 and 4 are used to indicate the equation concerned when such information is important.
[6] Reference 2, p. 55.

In a similar way, Birge's point of view[7] is revealed in his criticism of certain adoptions of the International Electrotechnical Commission (I.E.C.) and the Committee on Symbols, Units and Nomenclature (S.U.N. Committee) in which he said:

> "The numerical value of μ_0 varies in these systems, but in all of them as in the original Maxwell system where $\lambda_0 = 1$, this magnitude is, by definition, without dimensions. The discussions of the I.E.C. centered on the question as to whether the physical quantities B and H were of the same character or not. In spite of H. Abraham's clear and convincing reports to the contrary, the I.E.C. decided that B and H [without regard to the system under discussion] had different physical characters. I do not agree with this decision, . . ."

It should be noted that throughout, Birge refers to the dimensions of units rather than of physical quantities, as is done in this paper and is done by others as well.

Despite the thought which has been given to the subject, there still seems to be lacking in the literature a set of criteria and a method for determining what concepts and what units are most convenient in presenting *physics*, not a subdivision thereof, *as a single consistent whole.* This paper is concerned with certain of these criteria and their application and is based on the principle that the subject matter of physics, if and whenever fully understood, will constitute *a single consistent whole.* In describing parts of the whole and in relating them to one another, we therefore attempt to do so in such manner as to yield this consistency. It was in accord with this principle that physicists in succession introduced the ideas that an ether exists, that dielectrics such as oil "weaken the ether" within them, and that such dielectrics polarize in the presence of electric charges.

The criteria that are applied to determine whether or not our procedures are in accord with the demand for a *consistent whole*, as we see it, may be various. In this paper, we shall limit ourselves to three. Satisfying them requires:

[7] Reference 3, p. 178.

1. That those physical quantities which enter *physically* as a sum or a difference to yield another physical quantity shall each be of the same physical nature as is the physical quantity which is the sum or difference;

2. That physical quantities, except perhaps such as are dimensionless, shall be completely determined as to their natures by their *complete dimensional* formulas;[8]

3. That those physical quantities which enter physically as a sum or a difference to yield another physical quantity shall all be ascribable to separate physical processes or conditions or states in case any one of them shall be so ascribable.

With regard to criterion 3, it is to be understood that it may be rather difficult to interpret the terms as they appear in a written equation, that by certain rearrangements interpretations become practicable, and that when such interpretations are possible, this test is considered satisfied. Even with this privilege of rearrangement, one may not always be able to solve a problem acceptably. However, it would seem that of two competing formulas, only one of which is capable of detailed interpretation, that formula is the more acceptable which may be so interpreted.

Before proceeding to the main purpose of this paper, namely, the application of these criteria to concepts of the dielectric constant, we may discuss some of their general implications.

We may first take note of a criticism that has been advanced, namely, that since otherwise we have no definition for the term "nature of a physical quantity," criterions 1 and 2 essentially form a definition of that term. This must be conceded unless one, as does the writer, thinks of the term as something like length or time, indefinable in terms of simpler concepts. It is, of course, on this latter basis that this paper is presented.

The first criterion relating to sums and differences states that, if P, Q and R are physical quantities which are related by the equation

$$P=Q+R, \tag{5}$$

then P, Q and R are of the same physical nature. Illustrations from the field of mechanics, heat and current electricity are found in the familiar equations,

$$s=v_0t+\tfrac{1}{2}at^2, \tag{6}$$

$$H=mL+cm(t_2-t_1), \tag{7}$$

$$E=RI+L(dI/dt)+(Q/C). \tag{8}$$

On the other hand we are familiar with the fact that an equation such as

$$s=v_0t+\tfrac{1}{2}at^2-v+v_0+at \tag{9}$$

may be written for a discussion of motion with constant acceleration and that it seems at first glance to violate criterion 1. That the stated criterion should not be so violated by subterfuge is responsible for the second word of the phrase "enter physically;" for, however completely one may agree that the last three terms of the right hand member enter mathematically in the determination of s, no one will say that they enter physically.

Some may be inclined to take issue with criterion 1 as stated on the basis of the meaning of the term "physical nature." They may contend, on the one hand, that *density* and *specific gravity*, for instance, are of the same physical nature though they are not physically additive (strictly speaking the converse of the criterion need not hold, though that will not be argued here); and, on the other hand, that *temperature coefficient of resistance* and *temperature coefficient of expansion* are not of the same physical nature and yet are additive as, for instance, in the following equation for the temperature coefficient of resistivity of the material of a wire,

$$\frac{1}{\rho}\frac{d\rho}{dT}=\frac{1}{R}\frac{dR}{dT}-\frac{1}{l}\frac{dl}{dT}+\frac{2}{r}\frac{dr}{dT}. \tag{10}$$

The answer is that, to the writer, density and specific gravity are not of the same physical nature, whereas the two temperature coefficients are of the same physical nature. For lack of a better term, it is hoped that those who are not satisfied with the statement as a criterion, may look upon it for the purposes of this paper, in

[8] The term "complete dimensional formulas" is intended to include vector characteristics, those characteristics which are described by the phrases polar vector, axial vector, pure scalar, pseudo scalar, or tensor [Abraham and Föppl, *Theorie der Elektrizität* (1907), pp. 8–10]. Though not included in Bridgman's classic discussion of dimensions, use of this characteristic has been made by different authors. Birge's conclusion (Reference 3, p. 179) that units of work and of torque have the same dimensions, assumes that vector characteristics are not dimensional characteristics.

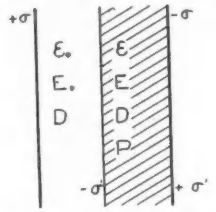

FIG. 1. Two infinite parallel condenser plates with electric surface-charge densities of $+\sigma$ and $-\sigma$, with the interspace evacuated except for the parallel-sided dielectric slab (shaded area) whose dielectric constant is ϵ or k/j.

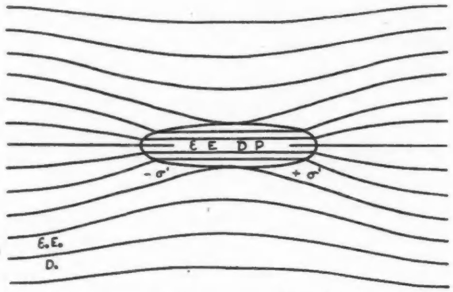

FIG. 2. A much elongated ellipsoidal dielectric with a dielectric constant ϵ in an evacuated space of infinite extent where, except for the effect of the ellipsoid, the electric field would be uniform and parallel to the major axis of the ellipsoid.

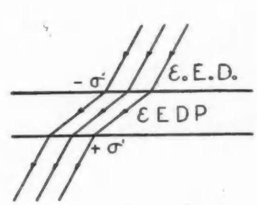

FIG. 3. A portion of a dielectric slab in free space with an electric field directed other than normal to the boundary.

accord with what has been said previously, as part of a definition of the term "physical nature."

In theory, Q and R of Eq. (5) might include additive terms (for example, the imaginary component of a complex quantity) which might annul one another through being equal in magnitude but opposite in sign, and thus result in Q and R, somewhat as in connection with Eq. (9), being different from P in nature. Among physical equations which are intended to represent general relations, none that the writer is aware of is of such a type.

Criterion 2 will not be generally conceded. Some will take issue with it because it declares Young's modulus and the volume modulus to be quantities of the same physical nature, since their physical dimensions are the same. It is agreed that they are simply related to each other by means of the numeric Poisson's ratio, though it may not seem so certain that the relation is as simple as that between the emitted radiance from the surface of an opaque radiator and the internally reflected radiance from the same surface, both of which may be related to each other separately by the absorptivity, the emissivity, or the reflectivity of the material. Perhaps whether or not one will accept the criterion will depend on whether or not he sees a parallelism between the modulus and the radiance illustrations.

Attention should be given to the fact that many speak of dimensions of physical quantities in special systems as in the c.g.s. electrostatic system or the c.g.s. electromagnetic system where, respectively, capacitance and inductance are given the dimensions of length, a dimension which by itself certainly does not describe the nature of the quantity being discussed. The situation is well described by Fischer[9] who states, regarding such systems which employ but three independent dimensions,

"The separate absolute systems of measurement originate through definite, arbitrary assumptions regarding two of the three constants ϵ_0, μ_0, $\gamma[\gamma=c\sqrt{\epsilon_0\mu_0}]$. Thereby an arbitrary relation between units is established. This has as a consequence the reduction of the number of independent fundamental quantities from four to three whose dimensions are those of length, time and mass."

In such systems, whatever their justifications, there is evidently no attempt to present a system which views physics as *a single consistent whole* as is attempted here.

Criterion 3 is likely to be rather generally accepted. We make much use of it in presenting our messages to other physicists and to our students in the classroom. That Eqs. (6), (7) and (8) are susceptible of detailed interpretations is quite obvious.

In the application of the criteria, it has seemed convenient to start at the point where Webster left off, namely, with his conclusion, which has seemed rather unsatisfactory, that it is a matter of convenience whether or not one adopts Eq. (3) or Eq. (4).

For the present let us assume j to be dimensional. Satisfaction of the first criterion by Eq. (3) requires that D and E shall be of the same

[9] Fischer, Zeits. f. Physik **100**, 360 (1936).

nature and hence that D shall be a field strength if we declare E to be such. Satisfaction by Eq. (4) requires that D and P be of the same nature and that $4\pi P$ be a displacement if we declare D to be such.

From the standpoint of criterion 2, namely, that physical quantities shall be completely determined as to their natures by their complete dimensional formulas, one cannot speak definitely in favor of either Eq. (3) or Eq. (4). The criterion definitely declares, however, for dimensions for j in the first case, and for ϵ and ϵ_0 in the second; and further, in the second case, for a distinction in nature between the quantities D and E. More with regard to this criterion will appear later.

Preliminary to the application of criterion 3, let us consider three physical situations (Figs. 1, 2 and 3) that involve an isotropic dielectric. As here used the term dielectric does not include free space although such free space is said to be characterized by the dielectric constant ϵ_0.

In each of these cases the condition of the electric field is described by saying that the dielectric experiences a polarization P or, what is the same thing, by saying that fictitious or induced polarization charges with surface densities $-\sigma'$ and $+\sigma'$ appear at the surface of the dielectric. In Fig. 1, σ' and P are both uniform and equal. In Fig. 2, σ' reckoned per unit of area of the ellipsoidal surface is variable, though, reckoned per unit of area projected on a surface perpendicular to the field strength in the ellipsoid, it is constant and equal to P. In Fig. 3, σ' is constant and, when measured per unit of area projected on a surface normal to the field strength in the dielectric, is equal to P in the dielectric. While in the cases mentioned, where only uniform inducing fields are considered, the values of σ' and P are constant, such is not the case in dielectrics where the inducing electric fields are nonuniform. We may, however, conveniently limit the discussion to cases where P and σ', defined as the surface charge per unit of projected area taken normal to the field strength, are constant.

Previous to applying the criterion to electric displacements, we may well consider its application to the more easily comprehended electric field strength. Eqs. (3) and (4) yield directly

$$E=kE-4\pi jP=\epsilon E/\epsilon_0-4\pi P/\epsilon_0, \tag{11}$$

from which it appears that the interpretations of E that go with these two earlier equations are identical. For the cases where E is constant throughout the dielectric, Eq. (11) may be written as

$$E=\epsilon E/\epsilon_0-4\pi\sigma'/\epsilon_0, \tag{12}$$

where σ', in accord with what has been said, is the induced surface charge density taken over a projected area normal to P. Further,

$$E=4\pi P/(\epsilon-\epsilon_0), \tag{13}$$

which shows that the field strength at a point in a given dielectric always bears a definite relation to the polarization at that point. For convenience of the interpretations we shall make, Eq. (11) evidently may be written as

$$E=E_0-4\pi P/\epsilon_0+\epsilon E/\epsilon_0-E_0. \tag{14}$$

In this form it is easy to interpret the terms entering in the expression for the field strength in a dielectric, for our simple cases, as the vector sum of E_0, the external field that would exist in the absence of the dielectric, and the field due to the polarization of the dielectric, or the remainder of the right hand member of Eq. (14).

For the case of Fig. 1, $\epsilon E/\epsilon_0-E_0$ is zero and here

$$E=E_0-4\pi P/\epsilon_0=E_0-4\pi\sigma'/\epsilon_0, \tag{15}$$

which shows that $-4\pi P/\epsilon_0$, or $-4\pi\sigma'/\epsilon_0$, is the field strength due to polarization which occurs in the infinite parallel slab of dielectric polarized uniformly and perpendicularly to the sides of the slab. Its direction is opposite to that of P. Further, since $\epsilon E/\epsilon_0$ is here equal to E_0, we may say that $\epsilon E/\epsilon_0$, not only for the present case but whatever the situation, is that uniform field strength external to a parallel sided, infinite slab composed of the dielectric material under consideration, and oriented with its faces normal to that field strength which is associated with a field strength E in the slab. It is to be noted that no restrictions of interpretation hinder associating $\epsilon E/\epsilon_0$ with something outside the slab as there would be were E only being considered. Returning to Eq. (11) we may say that $-4\pi P/\epsilon_0$ and $\epsilon E/\epsilon_0$ have the interpretations just given, and that criterion 3 has been satisfactorily applied to the

general case described by that equation. Further application to field strengths for the cases of Figs. 2 and 3 is unnecessary.

Consider now the application of the third criterion of consistency to Eqs. (3) and (4) and to a uniform dielectric in free space. With regard to Eq. (4), it states that the displacement D_4 or ϵE occurring in the dielectric is equal to the displacement $\epsilon_0 E$ which would occur were the field strength E actually present and there were no polarization, plus the displacement $4\pi P$ resulting from the polarization accompanying the field strength E. There seems to be no difficulty.

With regard to Eq. (3), it is to be noted that since E is a field strength, both D_3 and $4\pi P/\epsilon_0$ are also necessarily field strengths. Therefore, the criterion when applied to Eq. (3) states that the field strength D_3 is equal to the field strength E occurring in the dielectric plus a field strength connected with a polarization $4\pi P/\epsilon_0$. There is difficulty here. In the general case, one sees no field strength in the dielectric which D_3 is thought to characterize that can be associated with it and is equal to it in magnitude.

With the expectation that the difficulty of the general case for D_3 may clear up in the application of the criterion to special cases, let us consider the case of a thin slab of dielectric between two parallel condenser plates. Here from the standpoints of magnitudes of quantities, Eqs. (3) and (4) may both be considered equally verified. Since Eq. (4) presented no difficulty in the general case, it will present no difficulty here. From the standpoint of Eq. (3), we may say that the field strength D_3 just outside the slab is equal to the actual field strength inside the slab plus the reduction in field strength that occurs there due to the polarization. Instead of referring the field strength D_3 to a condition outside the slab, we may say that it is the field strength that would exist where the slab is if the slab were removed and the external field were to remain unchanged. While it seems thus possible to apply criterion 3 to Eq. (3) for this special case, the application is not completely satisfactory; for the quantity D_3 is meant to apply to the interior of the slab, and actually to represent a condition existing there and not one that would exist there were some other conditions true.

Consider next the application of criterion 3 to a slender ellipsoid of dielectric in an otherwise infinite uniform field with its long axis parallel to the field (Fig. 2). Here again there is no difficulty so far as Eq. (4) is concerned. But from the standpoint of Eq. (3) there is difficulty. First, one cannot interpret D_3 as the field strength that would occur where the ellipsoid is, were the ellipsoid removed, for E in the case of the infinitely slender ellipsoid has that value. Second, the only place where a field equal to D_3 in magnitude occurs is just outside the ellipsoid at the places where the long axis intersects its surface. Certainly, here a field strength interpretation for D_3 is not a happy one. When we consider a more difficult situation, one in which, for instance, a parallel sided slab of dielectric of infinite extent is oriented unsymmetrically with respect to the electric field in what would otherwise be a uniform infinite field (Fig. 3), the discovery of a reasonable field to which one may ascribe D_3 is quite out of the question.

If, in seeking a justification by criterion 3, one postulates, in accord with a common procedure, a narrow slot cut in the ellipsoid with its faces perpendicular to the field, he will have a portion of space where a field strength numerically equal to D is found. It should be noted, however, that the system which yields this field strength *is not exactly equivalent to the ellipsoid;* that the field strength thus attained is due in part to parallel layers of induced surface charge produced at the bounding surfaces of the slot by the polarization of the dielectric; and that within the ellipsoid proper, even though near the slot, the separate contributions of these layers of surface charge annul each other. Whether or not one accepts criterion 3, it seems that this particular illustration involving the slot cannot be used to show that this criterion in any way leads to the identification of D with a field strength. Of course, if one desires to define the D in the dielectric as the E in the slot, which I doubt many will be willing to do, the situation is different.

There seems, on the part of some, a tendency to look upon a displacement as a field strength because we cannot picture in our minds what it is like and cannot measure it directly, whereas the field strength to which it is always related can be connected with a mental picture and can be measured directly. In this respect, electric displacement is on a par with the wave function of quantum mechanics. It was defined and named at a time when an all pervading ether was assumed, and in line with that conception, it was not difficult to picture or to measure. Now, however, the picture is removed, though the physical quantity as a measure of a process, or a condition or a state still remains. As such, an electric displacement should be as much subject to criteria as is the more easily comprehended electric field strength.

It would seem, in view of the foregoing, that, unless one in effect defines the D at a point in a medium as the E of a narrow slot imagined cut at the point so that the field is at right angles to the sides of the slot, one must conclude that the criteria speaks definitely in favor of Eq. (4) and of regarding D as essentially different in nature from E; and just as definitely against Eq. (3) and of regarding D as a field strength.

The assumption that j is dimensional, which has been taken as granted in the foregoing, itself merits discussion. Webster has intimated, without favor however, that it is possible to regard j as dimensionless. The suggestion here is that, by arbitrary definition of the escoulomb with the aid of the familiar coulomb equation, we may make the dimensions of the denominator of Eq. (2) precisely the same as those of the numerator. Consider, however, the consequences of this decision from the standpoint of criterion 2, namely, that physical quantities shall be completely determined as to their natures by their complete dimensional formulas. At once a certain difficulty appears, for the same treatment given to the coulomb equation for magnetism leads to the untenable conclusion that electric charges and magnetic poles are of the same nature.

Some try to evade the magnetic pole-electric charge difficulty by saying that in the electrostatic system the escoulomb is a $dyne^{\frac{1}{2}}\cdot cm$, while in the electromagnetic system it is something of a different nature, namely, $1/3\times10^{10}$ of a $g^{\frac{1}{2}}\cdot cm^{\frac{1}{2}}$; while the magnetic pole in the electromagnetic system is a $dyne^{\frac{1}{2}}\cdot cm$ and in the electrostatic system $(1/3\times10^{10})g^{\frac{1}{2}}\cdot cm^{\frac{1}{2}}$ if it is at all considered in the latter system. Recognition of the dimensions of j and of ϵ, however, permits one to write

$$1\ \text{escoulomb}=1\ \text{c.g.s. e.s. unit of } \epsilon\cdot\text{dyne}^{\frac{1}{2}}\cdot\text{cm}$$

$$=\frac{1}{3\times10^{10}}\frac{\text{g}^{\frac{1}{2}}\cdot\text{cm}^{\frac{1}{2}}}{\text{c.g.s. e.m. unit of }\mu}, \qquad (16)$$

and correspondingly for the unit magnetic pole. These expressions seem awkward, but merely because of our lack of names for the units of ϵ and μ.

Another consequence of a dimensionless j is that an esfarad is declared to be a *centimeter* and an esohm, a sec.$\cdot$cm^{-1}, etc., things which they are obviously not.

Of course, it may be pointed out that, as is true of all good equations, the equation[10]

$$c=1/(\mu\epsilon)^{\frac{1}{2}} \qquad (17)$$

holds true in the form given whatever the system of units, provided ϵ and μ are regarded as dimensional. That μ and ϵ are ordinarily expressed in different systems does not matter. Computations made for the purpose of obtaining numerical values must always of necessity involve the use of a consistent system of units. A disregard of dimensions for μ and ϵ, at best, can only lead to viewing physics as a group of subdivisions, each of which is largely but not completely self-consistent.

In agreement with Webster, I feel it desirable to think of j or $1/\epsilon_0$ as a constant of electrostatic; but, differing from him, as well as from Page and Adams, and from Birge, and with a feeling that the subject matter of physics, if and whenever fully understood, will constitute *a single consistent whole*, I think it desirable that we regard the electric displacement D as a quantity different in nature from the electric field strength E and, consequently, that we write the fundamental equation connecting them in the form

$$D=\epsilon E=\epsilon_0 E+4\pi P, \qquad (4)$$

or, if ϵ is to be written as "unscrambled," as

$$D=kE/j=E/j+4\pi P. \qquad (18)$$

The writer wishes to acknowledge his indebtedness for helpful discussion to his colleague, Dr. D. R. Inglis, and especially to his friend, Professor W. H. Michener who, though not always agreeing, has been particularly helpful by virtue of his searching questions and apt illustrations.

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[10] A form in which an arbitrary dimensionless factor appears additionally in the right-hand member is, of course, equally acceptable.

One-Hour Laboratory Periods in General Physics

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MUCH has been written recently on the conduct of courses in college physics.[1] Interest in this field is in the present instance due to admonitions from the administration to reduce costs. There is, fortunately, no single way to teach the subject. What is presented herewith is a way of teaching general physics to engineers that has proved satisfactory to the institutional administration, the members of this department, the school of engineering, and as far as can be judged, the students. The course prior to 1923–24 was a more or less conventional course with two demonstration lectures, two recitations and one two-hour laboratory period each week. The problem was to reduce teaching costs without impairing the effectiveness of the course.

The lectures might be reduced to one per week by minimizing the mathematical discussions and increasing, relatively, the time devoted to demonstrations. This change was introduced in the second year of an experiment that will be described.

No member of the staff was anxious to reduce the number of recitation sections, as it seemed that these meetings, in groups of 25 to 28, were necessary to talk things over, answer questions, work problems, and occasionally to ask questions. Opinions as to the value of recitation sections differ widely among teachers of the subject, as the author has had occasion to ascertain in conversation with friends at other institutions. That the recitation section is of real value at this institution was made very evident several years later, in 1933, when a comparative newcomer to the staff insisted that much of the work of the recitation should be done in the lecture. It was decided to try two demonstration lectures and one recitation per week, instead of one demonstration lecture and two recitations. This, of course, showed an apparent saving of three hours of instructional time per week, as the 109 students (the registration was low in both 1932 and 1933) were accommodated in one lecture rather than in four recitations. However, a time-study[2] showed that the students came to the instructors after class time for assistance to such an extent that the actual instructional time amounted to an increase of about 50 percent over the old schedule. Needless to say, the innovation was dropped at the end of the first term.

The laboratory seemed to offer the best opportunity for saving instructional time. Originally there was one large laboratory room with four or five different experiments running at a time, and several instructors on duty for sections of 40 to 60 students. "Checking in" at the instructor's desk at the beginning of a period to obtain an assignment and the necessary small pieces of apparatus, as well as "checking out" when returning the apparatus, required too much time; there was confusion and noise; the students showed a strong preference for the instructor that asked the least searching questions before signing data sheets; it was hard to keep apparatus in repair. The number of instructors in the laboratory was variable; when there were students waiting for attention, an instructor was added; when the instructors were not all busy, one would leave. An average of the instructor-to-student ratio showed that on this system one instructor could not take care of more than 16 students.

In 1922–23 the laboratory was run as far as possible with all students working on the same experiment at the same time. The apparatus that was duplicated for this educational experiment was of the kind that could be made at slight cost in the college shops. For example, for the study of the addition of forces there were provided 30 force tables with cast-iron tops and tripods that were cast, machined and graduated largely by students; the same number of "torque boards," each a 10-in. circular wooden disk with a piece of polar coordinate paper glued to it, mounted on a horizontal axis and provided with pegs to which to apply forces; 15 pieces to illustrate the addition of parallel forces, each with a counter-

[1] See D. S. Elliott, J. Eng. Ed. **26**, 463 (1936), and other references there given.

[2] See p. 71 of this issue.

weighted bar and 4 equal-arm levers for applying upward forces; 30 attachments for the force tables consisting of boards 1 ft. square with holes 1 in. apart horizontally and vertically, with pegs, strings and weights, to verify the addition of non-concurrent forces; and 15 wooden derricks, also to illustrate a problem in the addition of non-concurrent forces.

The sections were not restricted at registration time; there were 7 the first term ranging from 16 to 30 students each, and accommodating a total of 145 students. The instructors all reported that they had "nothing to do" with only 16 students in a section, and that they could handle about 24 (in one man's opinion 26) as easily as 16 on the old basis. The laboratories for general physics in the new building, occupied in the fall of 1928, are designed to accommodate 24 students each. This "even front" plan has been in use steadily since then for all courses in general physics. The scheme is not absolutely rigid; occasionally an exceptionally well prepared student is assigned a special project in lieu of some of the experiments. An incidental advantage, of course, is better coördination of the laboratory with lecture and recitation.

The next educational experiment undertaken was that of determining the optimum length of a laboratory period. The staff agreed that, from their own experiences at other institutions, a three-hour period in elementary work was too long. Was two hours the right length, or was one hour a possibility? It had always seemed to many of us that too much time was spent in boiling water, heating samples, stringing up pulleys, or standing in line to get a micrometer or a resistance box.

The objectives of the laboratory were discussed and the agreement reached that the main function of the laboratory was to be that of illustrating principles, and further that this could probably be done best at the beginning of the year's work by "verification" experiments, in which a problem is solved and the numerical results are verified within experimental error by means of apparatus. The apparatus for the addition of forces, already mentioned, is used for this purpose. After four or five weeks, the usual measurement-type of experiment is introduced, but always with apparatus of simple design. Adroitness of manipulation, deftness in computation, and the acquisition of methods of measurements are encouraged, but are regarded as of secondary importance.

The experiment was begun in 1923–24 and continued for a period of four years because major changes in the engineering curriculum were undertaken during this time. During the first two years of this period the electrical engineering students took their physics as freshmen, while all others took it as sophomores. In the third year of the experiment there were no electrical students in the course, as the subject was being transferred to their sophomore year in order to provide a common freshman year for all engineers. In the fourth year, all regular students were sophomores.

When the experiment was started, all students attended 2 lectures and two recitations per week; the special group met twice a week for one-hour laboratory periods, whereas the regulars met once a week for a two-hour period. The author decided to take the special laboratory group himself and chose a section for which a convenient time could be arranged in his own schedule; it happened to be a freshman electrical section. The following year, 1924–25, two sections of sophomores were chosen for the special laboratory work, neither one being taught by the author. The choice was based entirely on the possibility of arranging a suitable schedule. A complication was introduced into the experiment at this time by a request to have the students meet not more than five times a week; even this was regarded as a concession because engineering physics at this institution is only a three-credit course. Consequently only one lecture was given to these special sections. The third year three sections were taught by each method. The results, as shown in Table I, seemed conclusive, but due to a special request, the experiment was continued for one more year, the number of sections taught by the old and new methods being, respectively, two and seven. The two sections were given to the staff member with the longest teaching record.

An examination of Table I shows that the grades are slightly in favor of the new method, but that the difference is not significant. Both

TABLE I. *Two-hour versus one-hour laboratory periods in general physics for engineers.*

	Group I: 2 lect., 2 rec., 1 2-hr. lab.								*Group II:* 2 lect., 2 rec., 2 1-hr. lab.; after 1st year, 1 lect., 2 rec., 2 1-hr lab.							
	TERM I		TERM II		TERM III		AV. PER TERM		TERM I		TERM II		TERM III		AV. PER TERM	
YEAR	No.	Grade	No.	Grade	No.	Grade	No.	Grade	No.	Grade	No.	Grade	No.	Grade	No.	Grade
1923–24	213	63	158	69	160	70	177	67	22	72	24	74	26	76	24	74
1924–25	160	69	128	71	110	79	133	72	46	70	35	70	30	84	37	74
1925–26	52	68	42	70	14	82	36	71	59	66	56	71	55	83	57	73
1926–27	47	62	36	78	26	81	36	72	146	75	129	78	111	80	195	77

methods produce approximately the same results, but the new method requires slightly less time in class per week, is more easily scheduled (so the schedule committee states) and compels the student to spend some time on physics almost every evening. No preparation is needed for the Monday lecture, but laboratory as well as recitation needs preparation.

Since grades are used as a basis for comparison, the method of grading must be described briefly. A student's term grade is obtained by averaging his examination grade weighted 2, his recitation grade weighted 1, and his laboratory grade weighted 2. The examination grade is the average of three or four quiz grades and the final examination grade. The questions are not objective, but consist of definitions, derivation of formulas and (chiefly) problems. Most final examinations contain a question of another type; for example, the students are asked to criticize a short paragraph from some so-called popular science magazine or to write an article of 250 words on friction or some other topic. They are informed that the manner of presentation as well as the facts mentioned will be graded. One staff member reads one question on all papers. The recitation grade is based partly on problems worked in class, and partly on oral answers to questions.

The laboratory grade depends almost entirely on the laboratory reports. English, neatness, accuracy—all enter into the grade. In the two-hour laboratory system, about nine experiments were performed per term, and each was written up in detail, so that a student spent about an hour on a report in addition to the computations. In the one-hour laboratory system each student performs eighteen or nineteen experiments per term; two or three of these are written up in "full form," as just described. The rest of the experiments are written in a "short form" consisting of the data sheet, computations, and answers to questions asked in the laboratory manual. The actual time of writing one of these is about fifteen minutes.

It may be of interest to sketch briefly the course of events in a one-hour laboratory period. The students enter and take chairs near the blackboard. The instructor asks a few questions and makes a few remarks about the apparatus such as cautioning the students to keep their heads away from the neighborhood of a wire that might snap, or their feet somewhere else than perpendicularly below suspended weights; or giving instructions about preventing mercury spillage, using protective resistances, and the like. This may take five or seven minutes. The students are then sent to the apparatus. No time is lost. If the experiment is on specific heat, for example, the samples are hot when the students enter the laboratory. For electrical experiments, the apparatus is grouped on the tables so that the students can begin making connections at once. The instructor "circulates" about the laboratory, giving help where needed, noting absentees, and discussing reports of the preceding experiment that may not be satisfactory. In electrical experiments he looks over the wiring and, if found correct, closes the switch for each circuit. There are few experiments in use in any first year physics laboratory for which the data cannot be taken in 15 or 20 minutes provided that the students understand the principle of the experiment before they come to the laboratory. In many cases the students complete their slide-rule computations before the close of the hour.

In 1927–28 the plan of five one-hour meetings per week was adopted for all engineering sections. At the close of this year another major change was made in the engineering curriculum. Physics was transferred to the freshman year, and a

carefully planned, closely coordinated program was adopted for the courses in freshman mathematics, physics, and engineering problems. This necessitated several minor changes in the arrangement of the topics in physics, but not in the plan of five one-hour meetings per week. The coordination between physics and engineering problems is even better today than when started.

As a result of this experimentation, the original object has been attained: the cost of instruction has been materially decreased due to a smaller number of hours in class, larger laboratory sections, and a smaller apparatus repair bill. The work of the course, it is felt, has been improved by shortening the laboratory period. Several members of the staff have stated that they feel they do their best teaching in the laboratory; none of the present group would voluntarily return to a two-hour period. The only difficulty that has been experienced is that of training new laboratory assistants; the scheme that has been evolved is to assign the two or three sections first working each experiment to experienced men, thus giving the new men a chance to visit these sections and become acquainted with the method.

The Photoelectric Determination of *h* as an Undergraduate Experiment

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EINSTEIN'S equation for the photoelectric effect,

$$mv^2/2 = h\nu - W,$$

is the usual starting point for the presentation of quantum theory to undergraduates. The following comment by Hughes and DuBridge[1] would seem to justify this practice.

> "This equation is perhaps the most important single equation in the whole quantum theory, and is the key to a vast number of results outside the restricted domain of photoelectricity, as well as within it. Constant application of Einstein's equation in modern physics has made it so familiar and useful that we are apt to forget how revolutionary it was when it was first proposed."

The general exclusion of an experimental test of this equation from undergraduate courses in modern physics seems to be due to the complexity of the problem rather than to a feeling that it is unessential. Harnwell and Livingood[2] describe the experiment but they use a photoelectric cell that is beyond the resources of most college laboratories.

A cell to be suitable for this purpose should possess at least three characteristics. (1) The cathode should be photoelectrically sensitive throughout the most of the visible spectrum since quartz monochromators are not generally available. (2) The cathode should be almost completely surrounded by the anode; otherwise, when the anode is made negative the paths of the electrons will be such that they miss the anode entirely and it will be difficult to determine the intercept of the experimental curve. (3) The anode should be insensitive throughout the spectral range; otherwise, the photoelectric emission from the anode will entirely mask the cathode emission when the anode is sufficiently negative to stop most of the cathode electrons. Conditions (1) and (3) tend to be mutually exclusive since an alkali metal must be used to meet the first condition and it is difficult to deposit it on the cathode only.

Fig. 1 shows a cell in which the three conditions may be met reasonably well. Its construction and preparation are similar to that of a cell described by Schulze.[3] The anode *A* and cathode *C* were formed by the evaporation of a silver bead from a tungsten filament, the bead being located at the point *F* so that the area of the cathode was made relatively small and was pretty well surrounded by the anode. The window *W* was blown after cutting off the stem supporting the filament. The cell was then placed in an electric oven at about 300°C while the cathode was cooled by water circulation. A small

[1] *Photoelectric Phenomena* (1932), p. 7.
[2] *Experimental Atomic Physics* (1933), p. 220.
[3] Zeits. f. Physik **90**, 63 (1934).

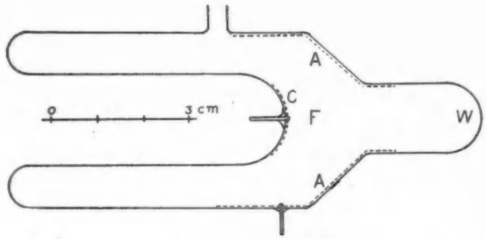

FIG. 1. Potassium hydride cell.

amount of potassium was evaporated into the hot cell. After the cell cooled hydrogen was admitted into the cell in order to sensitize it in the usual way.[4] The heating and sensitizing processes were repeated several times in alternation before the cell was finally sealed off. Fig. 2 shows that the saturation value of the inverse current amounts to about 3 percent of that for the direct. These curves were taken about ten months after the construction of the cell and indicate that the photosensitive hydride is fairly well anchored to the cathode.

Optical train.—The most convenient source of light is the mercury arc since the spectral lines 5770–90, 5461, 4916, 4358, 4046–78, and 3650A are well distributed in frequency. The cell was first mounted on the telescope end of a Hilger constant deviation spectrograph but it was found that lines 4916 and 4046A were too feeble to use and, of course, 3650A was missing entirely. It was decided to sacrifice definition for speed and a rough monochromator was assembled from miscellaneous parts. The telescope and collimator lenses were doublets with an aperture of 5 cm and a focal length of 30 cm. They were mounted in well-seasoned wooden arms on a large drawing board, the telescope arm being fixed and the collimator arm, which carried the lens, the slit and the lab-arc source, being free to rotate. The prism was made from selected plate glass cemented together and was filled with ethyl cinnamate.[5] A fixed exit slit 8×3 mm was used and the image of this was thrown on the cathode by a lens of short focal length. Filters[6] were introduced into the train immediately in front of the exit slit.

Electrical circuits.—The cathode was connected directly to the control grid of an FP54 tube which was incorporated in DuBridge and Brown's[7] bridge. The grid resistor had a nominal value of 3000 megohms. The galvanometer was a Leeds and Northrup type R with a period of 3 sec. and a sensitivity of 300 megohms. The system was sufficiently sensitive so that the gal-

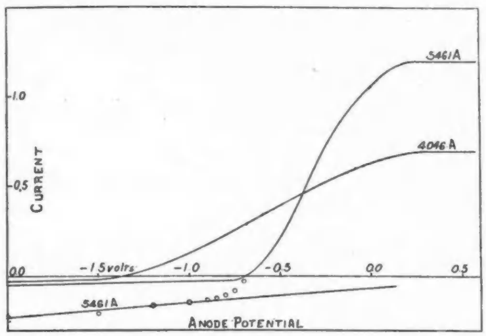

FIG. 2. Photoelectric current *vs.* anode potential, with cathode at ground potential. The points marked with circles are on a larger scale and show the method for separating the cathode and the anode emission.

vanometer shunt was set on 1/100 for the larger currents. The bridge was first balanced with the grid grounded and then the currents were measured by introducing between the ground and the grid resistor an additional potential difference ΔV from a standard potentiometer of the correct amount and sign to restore the balance. This procedure has two advantages over the method of measuring the currents by the galvanometer deflection. First, the over-all sensitivity of the bridge and galvanometer needs be neither constant nor linear; it is possible to change from one shunt setting to another at will with no check except an occasional one on the

[4] Hughes and DuBridge (reference 1, p. 172) indicate that there exists considerable latitude in the sensitizing process. Hydrogen was admitted through a palladium tube until a small tube-lighting transformer gave a strong glow discharge. This discharge was passed for a minute or so. Subsequent heating of the anode practically destroyed the sensitivity but a short glow discharge brought it back.

[5] This liquid has advantages over glass as its mean index of refraction is about that of crown glass and its dispersive power is half again as large as that of dense flint. It lacks the strong violet absorption of dense flint, for the system as a whole transmitted 3650A with about twice the intensity of 4916A. It is nonvolatile but unfortunately is a solvent for the ordinary cements. A satisfactory expedient is to cement the cell with de Khotinsky cement and then to evaporate chromium over the joints.

[6] The following filters are suitable: for 5770–90A, Corning HR Yellow Red Shade; 5461, Wratten 12; 4916, Wratten 4; 4358, Wratten 2A; 4046–78, Wratten 2; 3650, no filter.

[7] R. S. I. **4**, 532 (1933).

balance point. Second, the cathode of the photoelectric cell is always brought to ground potential and there is no need to correct for the potential drop across the grid resistor. In practice the bridge and galvanometer are much freer from random variations than the arc. Fluctuations of the order of 5 percent may occur in the arc intensity even after it has been operating with a storage battery source for an hour or more.

The typical curves shown in Fig. 2 indicate that the current reaches saturation for positive potentials of a few tenths of a volt. The saturation currents varied from about 2×10^{-11} amp., with 4916A, to 5×10^{-10}, with 5461A, but the slit was partly closed in the case of the latter line as its full intensity was not needed. The intercepts with the potential axis are quite clearly the potentials at which there are equal currents from cathode and anode.

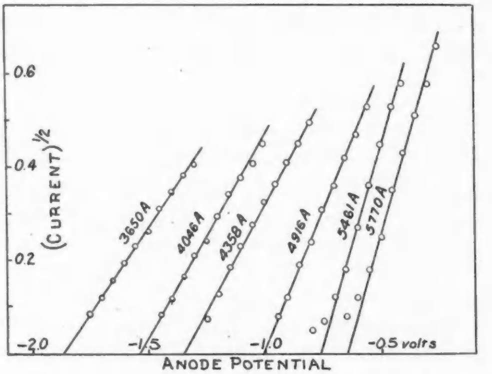

FIG. 3. The square root of the corrected current *vs.* the anode potential.

The intercept for the cathode current was determined by the following arbitrary procedure. The current for the larger negative potentials must be that due to anode emission only and evidently it is fairly linear with change of anode potential. A straight line is fitted to the linear part, plotted to an enlarged scale as is done for line 5461A in Fig. 2, and this line is used as the X axis for the cathode current. The determination of the intercept with this axis is carried out by the procedure suggested by Lukirsky and Prilezaev.[8] The square root of the corrected current is plotted against the anode potential, as in Fig. 3. To facilitate comparison the currents have been arbitrarily adjusted to a saturation value of 1.00. The intercept is then found by fitting straight lines to the plotted points.

There seems to be no theoretical reason for expecting these curves to be straight. In practice they are surprisingly linear over a fairly extended range of currents. (The ordinate 0.5 corresponds to 25 percent of the saturation current and the ordinate 0.1 to 1 percent.) The extrapolation to the intercept is confined in all but two cases to less than the last 1 percent of the current. The procedure, though admittedly arbitrary, may be justified on two counts: it affords a simple direct method for treating all the data alike; and it eliminates the personal error which enters when one attempts to fit a set of points with a curve which is not straight.

The intercepts as read from Fig. 3 are plotted in Fig. 4 against the frequencies of the spectral lines. The slope of this line determines h/e and is 0.396×10^{-14} volt·sec. This leads to $h=6.34\times10^{-27}$ erg·sec., if we take the electronic charge as 4.80×10^{-10} e.s.u. This value of h is about 4 percent too low but it is now recognized that there are inherent difficulties in the method of stopping potentials which were not envisaged by the earlier investigators. The experiment does, however, contain the essentials of the train of thought in which Einstein's equation made its first impact and this alone should justify its inclusion in an undergraduate course. More elaborate analyses, based on Fowler's method for instance, may well be introduced to the student at a more advanced stage in his careeer.

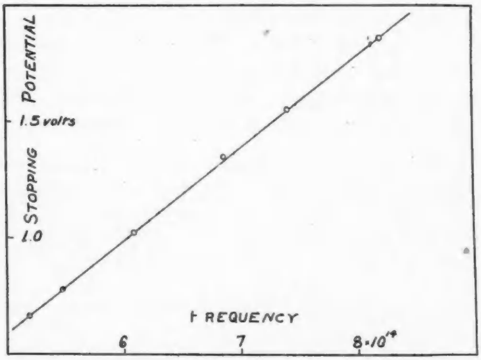

FIG. 4. Stopping potential *vs.* spectral frequency.

[8] Lukirsky and Prilezaev, Zeits. f. Physik **49**, 236 (1928).

The Early History of Graphs in Physical Literature

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Princeton University Library, Princeton, New Jersey

At least since the publication of Descartes' *Géométrie* (1637), functions of the continuous variables of mathematics have been associated with geometric curves. Graphs of relations between two measured physical variables seem to have had a much less conspicuous, and a surprisingly later, beginning. It may therefore be of general interest to put on record the following facts, collected as the result of a hunt for the first published Boyle's law curve. It would also be gratifying if their publication were to elicit further information on the subject.

The search for a graph in the works of Boyle and Mariotte and in the papers of Charles and Gay-Lussac proved fruitless, but Poggendorff's *Geschichte* pointed to a paper presented by Halley[1] to the Royal Society in 1686, "On the height of the mercury cylinder at any elevation," in which he says: "Expansions being reciprocally as heights of mercury, it is evident that by help of the curve of the hyperbola said expansions may be expounded to any given height of mercury," and he gives the figure for so doing.

Simultaneously with this lead, a totally different one was picked up in Preston:[2]

> "An exceedingly fertile and lucid method of treating many physical problems was introduced by Watt . . . known as the graphic method. . . . It was devised by Watt for the purpose of determining the work done by a steam-engine. Subsequently Clapeyron employed it to interpret the work of Carnot, and it has since been adopted and used with great advantage in every branch of science."

Watt,[3] one discovers, exhibited in a patent of 1782 a ruled rectangle, picturesquely framed by a longitudinal section of a steam-engine, on which he has drawn a curve of which he asserts:

> "The elastic power of the steam at the divisions marked in the length of said cylinder are represented by the lengths of the ordinates of the curve expressed in the decimal fractions of the original power. And I say that the sum of all these powers is greater than 57 hundred [th] parts of the original power multiplied by the length of the cylinder, whereby it appears that only 1/4 of the steam necessary to fill the whole cylinder is employed while the effect produced is more than 1/2 the effect which would have been produced by one whole cylinder full of steam."

From the internal evidence of the account, and from the fact that the instrument originally called by Watt an *indicator*, actually a pressure gauge only, was first described in writing more than ten years later,[4] the presumption is that the curve is not a copy of a mechanical tracing, nor a plot of measured values, but his intuitive estimate of the pressures. It is plainly, in any case, an integral part of the thinking which led him to utilize the expansion of steam.

As to Clapeyron,[5] he makes no mention of Watt, nor any other source for his idea. After quoting by name the work of his predecessors on the gas laws, he remarks that he has a new means of demonstrating these relations which he deems "worthy of the attention of geometers," and proceeds to describe in detail the construction of the P–V diagram now universally associated with the Carnot cycle, which is not in Carnot's memoir. As the volume of the gas increases at constant temperature "its pressure will decrease following the law of Mariotte . . . which may be represented by a curve CE of which pressures are abscissae and volumes are ordinates," to which he immediately refers without comment as an hyperbola. If the gas then expands out of contact with a heat supply its pressure will decrease more rapidly "suivant une loi inconnue," and the argument proceeds in familiar fashion from the figure.

Two years earlier an obscure Englishman, Meikle,[6] had published "An Improved Demonstration That Air Expands in Geometrical Progression for Equal Increments of Heat." Scoring Laplace and Poisson for mistakes in their investigations of the air therometer temperature scale, he adds this thrust, which probably, however, is

[1] Roy. Soc. Lond. Phil. Trans. No. 181, p. 104; Abridged, **2**, 15 (1722).
[2] *Theory of Heat* (1894), pp. 91–92.
[3] J. P. Muirhead, ed., *Origin and Progress of the Mechanical Inventions of James Watt* (1854), Vol. 3, pp. 60–63.
[4] H. W. Dickinson, ed., *James Watt . . . memorial volume prepared for the Watt centenary* (Oxford, 1927), p. 228.
[5] Paris. École polyt. J. **23**, 155 (1834).
[6] Phil. Mag. (2) **11**, 243 (1832).

not responsible for the paper by his noted French contemporary:

"It will also be seen that had these philosophers used a much more simple mode of reasoning,—something of the geometrical form aided by a diagram or two—they might have arrived at the only legitimate result of which the data will allow. But it is well known that a French mathematician would much rather run the risk of losing himself than employ any such means."

From a diagram which looks practically like a Carnot cycle, he proves that a hypothetical curve "such that whilst the temperature of a mass of air under constant pressure undergoes a change on the air thermometer, the corresponding change in quantity of heat is denoted by the area under the curve" is an hyperbola, and thence his thesis, by an argument conspicuously outmoded even though it is based on a graph.

Apparently one may follow the history of the gas laws from 1660 down to the days of Regnault before finding a graph of experimentally determined data. In Regnault's 1847 memoir[7] there unexpectedly appears a majestic plate, 80 cm square unfolded, showing to a very large scale experimental points on the P–V diagrams for several gases. These are presented with no preamble other than a detailed description of the scale chosen.

A similar history maintains for the one other relationship for which beginning students are sure to be required to plot their data, Hooke's law. The original observations were published concealed in an anagram rather than exhibited in a graph, and one follows the development of the subject down to Weber's paper[8] containing the first description of after-strain (1841) to find a graph, in this case elongations of a wire as a function of the time.

The wide divergence in time between the first two graphs found, Halley's and Watt's, suggested a check of the *Philosophical Transactions* and the *Mémoires* of the Paris Académie over this interval, a total of one hundred eighty rather liberally illustrated volumes. Aside from a few barometer charts, two papers by Wallis on theoretical mechanics and two papers on calculation of eclipses, ruled out from our point of view as being applications to algebraic equations rather than physics, just one instance was discovered. In an article on ballistics read before the Royal Society in March, 1781, the ingenious Mr. Benjamin Thompson[9] has three good graphs of experimental data, one bearing on speed of recoil with varying charge, two on the speed of the bullet as a function of its weight showing that the inverse "subtriplicate" law fits the observed data better than the inverse "subduplicate" law. Since this work was made public, and perhaps was in print, a few months before Watt's patent, it becomes necessary at least to bracket the names of the two inventor-physicists on this score.

The corresponding German set of this period, *Acta eruditorum*, is more sparsely illustrated. On the plates of figures which look like geometrical figures only, there may be a graph, but to locate the text associated with the diagram in order to prove the point would be an entirely prohibitive labor; this set was for this reason passed over.

To follow somewhat the subsequent history of the subject, a further survey was made of the *Philosophical Transactions*, and of *Philosophical Magazine*, *Annalen der Physik*, *Annales de Chimie et de Physique*, and *Journal de Physique* from the beginning of each, somewhere between 1780 and 1800, down to 1840. The Royal Society *Proceedings* of this period are abstracts only. One comes with fair frequency upon barometer[10] and thermometer charts, a plot of the variation in the earth's magnetic field, the tides, seasonal rise and fall of water level in wells, and similar cases in which the independent variable is time counted arbitrarily in integers. Excluding these and cases previously mentioned, only the following twenty examples could be gleaned from a total of six hundred volumes. A dozen outstanding books of the period are even more barren of graphs; one finds a single graph among 580 figures, or none at all.

In early French journals[11] are three articles on areometers with graphs which could well be called nomograms: a graphical method for calibration of the stem from two

[7] "Relations de expériences . . . pour déterminer les principales lois . . . dans le calcul des machines à vapeurs," Acad. des sci., Paris. Mém. Vol. 21.

[8] Ann. d. Physik [2] **54**, 13 (1841).

[9] Roy. Soc. Phil. Trans. **71**, 316 (1782).

[10] The earliest noticed is for 1684: Phil. Trans., Abridged **2**, 46 (1722).

[11] Vallet. J. de phys. **33**, 245 (1788); Barré d'Orleans. J. de phys. **57**, 439 (1803); Hassenfratz, Ann. de chim. **33**, 112 (1799).

fixed points, and charts for translating areometer readings into percentages of alcohol at any given temperature. The evaluation of wines was evidently a highly developed art at the time.

Wollaston[12] (1800) sketches a graph to describe an hypothetical gradation in density between two liquids, and uses it to explain a refraction phenomenon.

Herschel[13] (1800) gives a solar energy distribution curve for the purpose of which he imagines a spectrum projected on the paper and then says "the ordinates express the proportional elevations which a set of thermometers would experience when placed in these situations in the spectrum."

Prieur[14] (1806) in an attempt to reconcile a three-color theory with continuous spectra, offers a diagram with colors prismatically spaced as abscissas, and arbitrarily drawn across the ordinates three overlapping lines of decreasing slope. He supposes "that the modification of the red rays on which their refractibility depends are represented by the ordinates marked off by the first line," etc. The envelope of the three lines of course suggests a dispersion curve.

Delaroche[15] (1812) drafts a cooling curve. "Ces résults sont en outre exprimés graphiquement par la courbe. . . ."

Flaugerues[16] (1813) in order to prove that the diffraction fringes produced by a wedge-shaped slit are strictly rectangular hyperbolas, plots to a different scale slit-width against fringe-width, and points out in passing the analogy of the capillary wedge.

Fresnel[17] (1819) makes use of graphs to exhibit his estimates of the variation of intensity of illumination in fringes from point to point on the micrometer scale.

Steinhäser[18] (1819) in a "Beweis dass im innern der erde ein planet befindlich ist" proves by constructing two graphs that his data for the diurnal variation of magnetic declination have the form of a cycloid, and hence *Q.E.D.!* This case is included as the only instance in which the author was definitely misled by his graph.

Herschel[19] (1820) in a paper on interference rings in crystals represents Newton's laws by a straight line at 45° through the origin, "length of fit of easy reflection" being abscissas and fringe width ordinates, with a corresponding experimental curve for sodium tartrate below and for apophyllite above this line.

Poncelot[20] (1825) writing on vertical water-wheels presents a graph with elaborate description of choice of scale to show that the speed of rotation is proportional to the "quantity of action" nearly to the point where the action becomes a maximum.

Babbage[21] (1826) uses a graph for representing a hypothetical decrease in magnetic field with distance from a pole.

[12] Roy. Soc. Phil. Trans. (1800), p. 241.
[13] Roy. Soc. Phil. Trans. (1800), p. 536.
[14] Ann. de chim. **59**, 241 (1806).
[15] J. de phys. **75**, 218 (1812).
[16] J. de phys. **76**, 292–293 (1813).
[17] Ann. de chim. (2) **11**, 365 (1819).
[18] Ann. d. Physik **61**, 77 (1819).
[19] Roy. Soc. Lond. Phil. Trans. (1820), pp. 85, 94.
[20] Ann. de chim. (2) **30**, 175 (1825).
[21] Roy. Soc. Lond. Phil. Trans. (1826), p. 495.

Perkins[22] (1826) puts his experimental data on the compressibility of water into a graph with the comment: "A curve line has been drawn through the points as near as could be done to preserve a regular curve. There are various irregularities observable, but as the original records remain upon the plate those who choose . . . have the means of drawing any other curve that may suit their view of the law." The opportunity is suggested of deducing an empirical pressure-volume law, but none is deduced.

Erman[23] (1827) studying the change of volume of Rose metal as it goes through the melting point remarks significantly: "Um sie anschaulicher zu machen habe ich von den zahlenwerthen eine graphische darstellung gegeben, ähnlich denen welche man so oft in der meteorologie gebraucht."

Plateau[24] (1835) with a discussion of retinal after-images draws a curve for which he says: "ses fluctuations seron évidemment figurées par une curbe d'une forme analogue à la figure. . . ."

Forbes[25] (1838) in a paper on radiant heat has a graph, showing coordinate rulings for observed retardation of one of the doubly refracted rays upon the other against the thickness of mica used. "It was then easy to select those points through which a straight line could most nearly be drawn representing the linear relation." He also "takes the sure but laborious method of ascertaining at a number of points between total and partial reflection the intensities of the reflected heat, and by constructing a curve . . . to discover graphically for what value of the former the latter increased most rapidly," thereby to determine the mean refrangibility of the radiation.

Draper[26] (1840) in an investigation of the "electromotive-power of heat" demonstrates by means of a graph that "equal increments of heat do not set in motion equal quantities of electricity," showing the characteristic forms of the thermoelectric curves for several different thermoelements. This is some twenty years earlier than Gaugain's paper to which these curves are attributed by Edser.

Lubbock[27] (1840) in a divided paper on astronomical refraction reproduces in detailed graphic form earlier data on vapor pressures, compares graphically two tables of mean refraction, and also compares a linear formula for atmospheric temperatures at varying altitudes with balloon data obtained by Gay-Lussac.

Joule[28] (1842) explains in his paper on "The Electric Origin of the Heat of Combustion:" "If we divide the straight line AB into ten equal parts [for ten voltaic elements] and at each division erect straight lines perpendicular to AB and proportional to the quantities of electricity, the principles of electric action demand that the line drawn through the extremities of those perpendiculars should be straight. Produce this straight line . . . and the straight line AX will indicate the number of pairs necessary to decompose water."

[22] Roy. Soc. Lond. Phil. Trans. (1826), p. 544.
[23] Ann. d. Physik (2) **9**, 566 (1827).
[24] Ann. de chim. (2) **58**, 399 (1835).
[25] Phil. Mag. (3) **13**, 110, 182 (1838).
[26] Phil. Mag. (3) **16**, 453 (1840).
[27] Phil. Mag. (3) **16**, 510 (1840), footnote; **17**, 279 (1840).
[28] Phil. Mag. (3) **20**, 107 (1842).

The statement of Preston may then apparently be accepted with these reservations. (1) While the conspicuous success of Watt's diagram is very likely the shining example which pointed the way for many, there is one clear case of a graph used for computation a hundred years earlier, and Thompson must independently have perceived the merit of the method and must have introduced the idea to a considerable audience. (2) While it is not true, as one might infer from Preston's words, that graphs were unknown in the interval 1782–1834, between Watt and Clapeyron, investigators as late as 1840 were only beginning to appreciate the varied serviceability of graphic methods.

Incidentally these findings scarcely justify the gibe of Mr. Meikle; to that date there are eight graphs to the credit of the assumedly abstract thinking of the French, and seven to the presumptively more concrete thinking of the English.

A Time-Study of the Teaching of Physics

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PERHAPS everyone who has taught any one of the laboratory sciences has felt that he is putting in more time and effort than his colleagues in the nonlaboratory fields. College administrators wish to do everything by rule and allow a fixed number of instructional hours per credit. Statisticians who may never have taught at all know that a section should meet as many times per week as there are credits in the course, that laboratory periods should rate $\frac{1}{2}$ when lectures and recitations rate 1, and that a full load for an instructor is 16 credits. They consequently inform a department head that he is over-staffed, when the department head feels that his men are putting in longer hours than those in other departments. He feels it, but he does not know it, in the sense of having adequate data to back his statements. With the object of ascertaining the facts regarding time spent in teaching physics at this institution, a rather extensive time-study was undertaken.

Preliminary information was collected in 1931–32 to determine a convenient form on which to accumulate data, for it is evident that if the recording process is too burdensome, the data will consist of guesses rather than facts. In addition, of course, the form should be such that the data may be readily assembled in different ways for interpretation. The form finally adopted was a cross-hatched sheet with 55 columns and 32 horizontal lines—one for each day of the month and one for totals. Of the columns, 48 were headed as indicated in the following list, the remaining 7 being distributed among the different groups of headings and left blank so as to serve for the recording of unusual duties or activities.

Instruction

Course number and title
- Lecture and set-up
- Lecture preparation
- Recitation and paper work
- Recitation preparation
- Laboratory and set-up
- Laboratory reports
- Notes, new experiments, etc.
- Student conferences

(Repeated three times as one man may teach three courses. Duplicate sections in any course are recorded together.)

Thesis, research and other courses maintained by conference method

Administration

Department
- Staff meetings
- Student conferences not on subject matter
- Shop and laboratory supervision
- Errands
- Care of building, etc.
- Technical letters
- Office: letters, orders, telephone, etc.

School
- Staff meetings
- Committees
- Reports
- Student adviser

Institution
- Staff meetings
- Committees
- Reports
- Registration duties

Service

Societies (campus and professional)
Talks and their preparation (radio, clubs, etc.)
Conference with other departments
Visitors

Advancement

Seminar, including preparation
Reading, not directly for courses
Research
Preparation of texts, etc.

Data were collected throughout 1932–33 and 1933–34, the preliminary experience having indicated that there is no such thing as a "normal week" or "normal fortnight." During both years the enrollment was far below normal. The number of students per instructor for these years was also low: 38.4 and 42.0 compared to an average for the preceding ten years of 43.5. Due to the establishment of the Oregon state system of higher education in 1932, there was an interchange of several staff members between this institution and the University of Oregon; this made it very convenient to gather some data at the university as well as at the college, and I am endebted to the university physics staff for its whole hearted cooperation. Both institutions are organized on a basis of terms and credits, rather than semesters and semester hours.

After a little practice the staff members for the most part fell into the habit of recording the time in hours and tenths just before leaving the building at noon and at the close of day. Unfortunately two staff members were so constituted that they could not keep adequate data continuously. Their work consisted partly of recitation and laboratory sections in the general course for engineers and partly of upper division and graduate classes. Since their share in teaching the engineers was relatively small, it is felt that the lack of their records does not materially affect the conclusions regarding that course; where totals were needed, it was assumed that these men used the same time as the average of the other instructors. As far as their advanced work is concerned, the best that could be done was to make an estimate based on partial data. The data for the second year are far more nearly complete than for the first year.

No complete analysis of the data is attempted here, but a few numerical values are given that may have more than local interest. Table I compares the department programs for the years 1932–33 and 1933–34. The column headed average hours per term includes time spent by instructors in and out of class, and paid (student) help for moving apparatus to and from the stockroom and making minor emergency repairs. The number of hours needed during one term to teach one credit to one student evidently clusters around two values: between 2 and 3 and between 4.5 and 6.5, approximately. There are also

Table I. *Comparison of college programs for two successive years.*

Course	Credits per term	1932–33			1933–34		
		Av. no. students per term	Av. hrs. per term	Hrs. per term per student per credit	Av. no. students per term	Av. hrs. per term	Hrs. per term per student per credit
General phys.							
Engineers (regular)	3	90	715	2.6	116	829	2.4
Engineers (trailer)	3	12	158	4.4	8	150	6.2
Home economics	5	5	142	5.7	Dropped	—	—
Pharmacy	3	9	133	4.9	Combined with science		
Science	4	50	529	2.6	48	394	2.1
Phys. measurements	3	4	78	6.5[3]	8	256	10.7
Intermediate phys.	3	4	78	6.5[3]	—	—	—
Classical theories[2]	3	—	—	—	4	110	9.2
Photography (av. of 6 diff. courses)	ref. 1	31	328	4.2	20	220	4.8
Astron. and meteor.	3	31	218	2.3	10	130	4.3
Radio	3	14	226	5.4	15	186	4.1
Acoustics of bldgs.	3	3	102	11.3	Alternate years only		
Modern phys.	3	6	116	6.4	Merged to 4 cr., with lab.		
Modern phys.	3[2]	6	100	5.6[3]	6	160	6.7
Optics	3	—	—	—	4	77	6.4
Cosmic phys.	3[2]	5	100	6.7[3]	Alternate years only		
Modern phys. theories[3]	3				3	170	18.8
Thermodynamics	3[2]	5	144	8.0[3]	Alternate years only		
Theory of electricity	3	—	—	—	4	96	8.0
Theses, research and conference courses	—	—	—	6.0[3]	—	—	5.7

[1] Almost exactly half in 2-credit and half in 3-credit courses in 1932-33, and approximately $\frac{1}{3}$ in 2-credit and $\frac{2}{3}$ in 3-credit courses in 1933–34.
[2] No laboratory.
[3] Data not kept regularly; numbers are largely estimates.

scattering values above 8. The values below 3 all occur in courses with many students. Values between 4.5 and 6.5 seem to indicate normal conditions in small courses, and those above 8, abnormal conditions.

During the first year of the study, there were, as indicated, four different courses in general physics and, in addition, a "trailer" course (open to all, though primarily for engineers) that started the subject at the beginning of the winter term. The values of the index for three of these fall in the small-class group; one was dropped, another combined with the science group, and one maintained for the benefit of irregular students. Physical measurements runs too high in 1933–34 due to a very awkward schedule. Intermediate physics was replaced by classical theories in 1933–34; the first year that a course is given, it may be expected to consume an exceptional amount of time. This is also illustrated by the course in radio, which was assigned by force of circumstances to a new man in 1932–33; it is down in the normal range in 1933–34. The courses in photography will always remain in the "small course" group because the laboratory sections cannot be larger than 8 or 9. Astronomy changed from the one group to the other when the enrollment dropped to one-third of its former value. The courses having values above 8 were scrutinized, certain conditions changed, and their excessive cost reduced.

At the university, data collected during the winter and spring terms of 1932–33 yield the figures shown in Table II. The number of hours, 2.4, needed in a term to teach one credit to one student in general physics is the same as that at the college. For advanced work the value, 10.2, is somewhat higher. The survey course in physical science is a nonlaboratory course consisting of three demonstration lectures and one recitation per week; since it is not taught in the department of physics at the college, no direct comparison can be made.

Another index that is of value in estimating costs and instructional loads is the ratio (hours outside of class)/(hours in class). This ratio was determined for lecture, recitation, and laboratory separately. For example, in general physics, whether taught to engineers or others, the

TABLE II. *University program for two terms.*

Course	Credits per term	Av. no students per term	Av. hrs. per term	Hrs. per term per student per credit
Phys. science survey	4	199	659	0.8
General phys.	4	46	446	2.4
Advanced phys.	3	4 }	215	10.2
Conference courses	3	3 }		

quotient for demonstration lectures is 2.3, for recitations 1.5, and for one hour of laboratory 2.3. These figures mean that it takes on the average 2.3 hours to set up and tear down (but not repair) the apparatus for a 1-hour lecture; if the lecture is repeated, the only additional time is the hour required to give it. The 2.3 hours must be allowed in the program of the instructor giving the lecture or in that of some other qualified person. For the recitation sections, the 1.5 hours is spent almost entirely in student conferences, and in reading quiz papers; if an instructor has several sections, this 1.5 hours must be allowed for each. The 2.3 hours per hour of laboratory should be separated into: preparation and time for reading reports, 1.5 hours; everything else, 0.8 hour. The latter includes moving apparatus to the laboratory and back to the stock room, minor repairs, preparation of laboratory directions and working up new experiments. Some of this work is done by the man in charge of the laboratory, and some is done by students. Laboratory instructors should be allowed 1.5 hours outside for each hour spent in the laboratory. The man in charge of the laboratory should, in addition to the foregoing, be allowed 2 hours for each section requiring a new set-up. It is seen that except for new set-ups one hour in the laboratory and one hour in recitation require the same total amount of the instructor's time.

For advanced work, this quotient lies between 2.5 and 3.0 for lectures (not demonstration), and between 1.5 and 2.0 for laboratory sections. A very exceptional case is photography, with a laboratory ratio of 0.1; from the nature of the work, the instructor's laboratory tasks are practically completed at the close of each laboratory period.

This ratio also serves to indicate when it may be wise to change the schedule on which a course

is taught. If the value of the ratio is too high, it may be possible to reduce costs by increasing the number of periods spent in class. A case in point was furnished by a deviation from the usual manner of conducting the course for engineers. Instead of one lecture and two recitations per week, two lectures and one recitation were tried, with no change in the laboratory. For this experimental term the ratio was 3.1 compared to a normal 2.3. The increase was caused by the unprecedented number of conferences asked for by the students. The following term, when the old schedule was resumed, the ratio dropped to 2.2 and the number of hours per term per student per credit, from 2.5 to 2.3. The bearing of this on the arbitrary rule in use at many institutions of having the number of class meetings per week equal the number of credits, is evident.

At the university, general physics was a four-credit course, with two demonstration lectures, one recitation and one three-hour laboratory period. The ratio (hours outside of class)/(hours in class) was 2.9 for lecture, 4.9 for recitation, and 3.0 for laboratory. The figure for recitation seems high; the total instructional time could probably be decreased by adding another hour of recitation and thus reducing the time spent in student conferences. The figure for the laboratory is about the same as that at the college, and leads to the general conclusion that a total time of about three hours is needed outside for each hour spent in the laboratory no matter whether the laboratory period is one, two or three hours in length.

For advanced physics, the ratio is 6.1, and for the survey course, 1.0 for lecture and 7.7 for recitation. The abnormally low figure for demonstration lectures in the survey course is due to the fact that each lecture had to be given four times on account of the lack of a lecture room of adequate size. If the total time for preparing lectures be divided by the number of different lectures, the quotient is 3.2, which is not very different from the ordinary ratio for a demonstration lecture.

The numerical values that have been given agree fairly well for the two departments at which data have been gathered, but it is not claimed that the same values will apply to all institutions. No discussion is included of the relative amounts of time spent in teaching, administration, research, etc. as these are deemed to be chiefly of local interest. A few problems whose solution is aided by the results of a time study, have been indicated; others will occur to everyone interested in department administration.

The Eye as a Part of the Optical System of the Microscope and the Telescope

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THIS discussion of the behavior of microscopes and telescopes is essentially the treatment which I have used in my teaching and thinking for many years. It seems to me to be an approach which leads readily to an understanding of the performance of the instruments. The telescope seems to me particularly difficult to understand unless one traces the light through the instrument to the final image on the retina of the eye.

The Microscope

The unaided eye.—The optical system of the eye is far from simple, but for an elementary discussion of the relation of the microscope and telescope to vision, it is feasible to represent the eye as a simple camera obscura, with a thin lens. The depth d of the camera may be assumed to remain constant, the strength of the lens being changed in order to obtain a good focus with objects at various distances.

If an object of size L_0 is placed before the eye at such a distance D that the image is in focus on the retina, Fig. 1 represents the way in which the image is formed. The size L_I of the image on the retina is

$$L_I = L_0(d/D). \qquad (1)$$

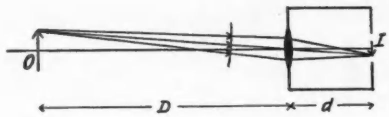

FIG. 1. Unaided eye.

It is fairly obvious, without detailed discussion, that the distinguishable detail in the object will be increased by increasing L_I and hence that, for close inspection, the distance D should be made as small as possible without impairing the sharpness of the focus. It may be verified by trial with any group of college students that for young persons with normal eyes the closest distance of distinct vision is about 25 cm. In this case Eq. (1) becomes

$$L_I = L_0 \cdot d/25, \tag{2}$$

where d must be expressed in centimeters. This relation may be assumed to give the size of the image on the retina when an object is being inspected to best advantage by the unaided eye.

The image on the retina is upside down, but we have become accustomed to this inverted image and normally interpret it in terms of surroundings which are right side up.

The simple microscope.—A simple lens or lens system may be used to enlarge the image on the retina, ordinarily without impairing the sharpness of the image, and hence to increase the detail which may be distinguished. Fig. 2 represents such a case, where the object is placed at the principal focus of the auxiliary lens. From the figure it appears that the size L_I' of the image on the retina will be

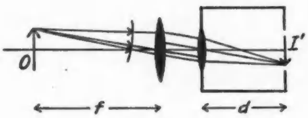

FIG. 2. Simple microscope.

$$L_I' = L_0 \cdot d/f. \tag{3}$$

The useful magnification M for young eyes, obtained by eliminating L_0 and d between Eqs. (2) and (3), is

$$M = L_I'/L_I = 25/f. \tag{4}$$

Obviously the useful magnification for old eyes, where the closest distance of distinct vision may be of the order of perhaps a meter, will be several times this figure.

In writing Eq. (3), it is assumed that the lens of the eye is adapted so as to give distinct vision for distant objects; in other words, that the eye is focused for parallel light. This is not the assumption usually made in our elementary textbooks, but it seems to me that it is the proper assumption. When the eye is focused for distant objects, the muscles are not under strain, but are relaxed. As a consequence, when so focused, the eye is capable of observing phenomena or of reading scales for long periods of time without tiring. It is important that the eye be so focused in making observations with the microscope or the telescope; and it is desirable that the beginner in laboratory work should become acquainted with this consequence of the way in which an eyepiece is focused, and thus be enabled by proper focusing to save his eyes from unnecessary strain. If, in adjusting an ocular, the cross hairs are first brought into sharp focus and the lens and the cross hairs are then separated as far as possible without impairing the definition or introducing conscious strain in the eye, the desirable ocular adjustment will be very nearly obtained.

The assumptions usually made in discussing the performance of a simple microscope are (a) that the eye is in focus for an image 25 cm from the eye, and (b) that the distance between the simple microscope and the eye is small in comparison with 25 cm. With these assumptions the size L_I'' of the image on the retina will approach the value

$$L_I'' = L_0 \cdot \frac{d}{D} = L_0 \cdot \frac{d}{f}\left(1 + \frac{f}{25}\right), \tag{5}$$

and the magnification will be

$$M = L_I''/L_I = (25/f) + 1. \tag{6}$$

It is interesting to take a reading glass and a printed page, and to observe the multitude of magnifications that can be gotten by holding the glass at distances from the eye which are not small in comparison with 25 cm.

The compound microscope.—The optical system of a compound microscope is sketched in Fig. 3, and from this and Eq. (3) it is evident that the

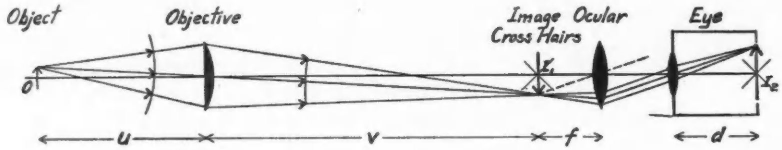

FIG. 3. Compound microscope.

size of the image on the retina is

$$L_2 = \frac{v}{u} \cdot \frac{d}{f} \cdot L_0, \tag{7}$$

and hence, for young eyes adjusted for distant vision, that the magnification is

$$M = \frac{L_2}{L_I} = \frac{v}{u} \cdot \frac{25}{f}. \tag{8}$$

By increasing the ratios v/u and $25/f$, the magnification may be made enormous, but as long as we use visible light to form our images, there is no gain except as a matter of convenience in increasing the magnification beyond about 400. A similar remark would, of course, apply to the simple microscope, the numerical factor there being much smaller.

The Telescope

We use the microscope for the minute inspection of objects which may be placed for observation at any convenient distance; but in order to examine the details of an object which we may not approach closely, we must use a telescope. Of course, the telescope has another use in defining a line of sight in the reading of angles in the laboratory and in the field, but we are concerned here with its optical performance as an aid to vision.

The unaided eye.—In inspecting distant objects, the eye performs in the manner indicated in Fig. 4. Here it is assumed that a distant object —say a telegraph pole with a cross arm—forms an image in sharp focus upon the retina. If the object subtend an angle θ at the eye, the size of the image formed upon the retina will be given by the equation

$$L_I = d \cdot \tan\theta, \tag{9}$$

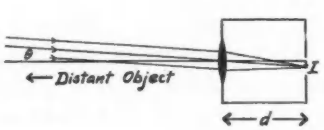

FIG. 4. Unaided eye.

where ordinarily the angle is small and may be substituted for the tangent, if that be preferred.

The astronomical telescope.—The manner of formation of the image of a distant object by a telescope of the astronomical type is sketched in Fig. 5, where the object looked at is the one supposed in the preceding paragraph to be viewed by the unaided eye. In this case an image I_1 of the object is formed by the objective at the cross hairs of the telescope, and the ocular is used as a simple microscope to form an image I_2 of I_1 upon the retina of the eye.

Fig. 5 shows the eye placed in such a position as to receive all of the light which passed through the telescope. The position is that of the *exit pupil* which, in the simple case here pictured, is the image of the objective formed by the ocular. With the eye so placed, the field of view is limited only by the size of the stop which is placed at the principal focus of the objective. Parenthetically, it may be remarked that those of us who wear spectacles are unable to get our eyes close enough to the ocular for the pupil of the eye to reach the exit pupil of the telescope, and that our field of view is thus cut down. It would be a boon to us if the makers of small laboratory telescopes would design their oculars so as to provide more space between the ocular cell and the exit pupil.

The size of the image formed on the retina, in the case shown in Fig. 5, is

$$L_2 = d \cdot \tan\theta' = d(F/f)\tan\theta, \tag{10}$$

where θ is the angle subtended by the object at the objective. For a distant object this angle will be essentially the same as the angle subtended at the eye, as shown in Fig. 4.

From Eqs. (9) and (10) it follows that the magnification of the telescope is given by the equation

$$M = L_2/L_I = \tan\theta'/\tan\theta = F/f, \tag{11}$$

if the eye is focused for parallel light. If the eye

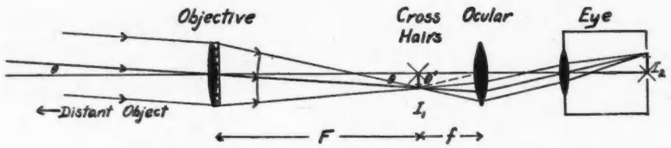

FIG. 5. Astronomical telescope.

be focused for 25 cm, the magnification will be larger, the value being

$$M=\frac{F}{f}\left(1+\frac{f}{25}\right). \tag{12}$$

As the telescope is ordinarily used its magnification will be between the two values here given. The difference may be detected in focusing a low power field glass.

The Galilean telescope.—Fig. 6 shows the type of telescope invented by Galileo and the manner in which it forms an image on the retina. Evidently this type of telescope forms an inverted image on the retina, as is the case with the unaided eye (Fig. 4). The astronomical telescope forms an image on the retina that is right side up, and thus opposite in sense to the image formed by the unaided eye. We speak of the Galilean as an *erecting telescope*, and of the astronomical as an *inverting telescope*.

In Fig. 6 the focal lengths of the objective and the ocular and the angle subtended by the object have essentially the same magnitudes as with the astronomical telescope of Fig. 5. The diameter of the objective in Fig. 6 is about a third larger, but even so, the pupil of the eye is only partially filled with light; only the shaded portion of the beam which enters the telescope reaches the retina. It is apparent that if the tip of the object were only a little farther off the axis, it would be entirely outside the field of view. A further increase in the size of the objective would increase the field of view, but a practical limit is soon reached. It may be taken as a general rule that the field of view of a Galilean telescope is inferior to that of the astronomical type, a difference which becomes increasingly great as the magnification is increased. Consequently the Galilean telescope finds its chief use as a low power field glass. It is compact, light in weight, and relatively cheap.

The expression for the magnification of a Galilean telescope is the same as that for the astronomical type. Eqs. (9), (10), and (11) apply in both cases. A skeleton sketch, which shows the angles involved, is added to Fig. 6. This sketch, which seems unnecessary in Fig. 5, should help in working out the expression for the magnification.

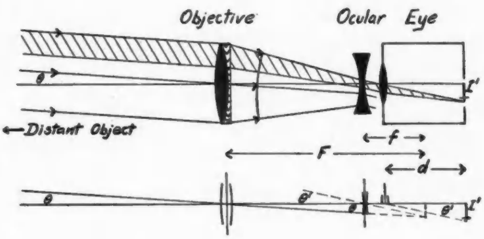

FIG. 6. Galilean telescope.

As with the microscope, there is a limit beyond which it is not desirable to increase the magnification of a telescope. A magnification of about 8 per centimeter, or of 20 per inch, of aperture should bring out all the detail which may be discerned with a telescope, and an increased magnification would only serve to diminish the brightness of the image without adding to the resolution of detail in the object.

The university is a nursery of scientific research and mental education, a place for the cultivation of ideals for students as well as for teachers. . . . Teachers and students of the university should consider it a great honor to be members of this organization.—WILHELM C. RÖNTGEN.

Diffraction of Light, an Experimental Demonstration

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A BEAUTIFUL photograph of diffraction rings for circular apertures admitting from one to twenty-five half-period elements from spherical wave-fronts of light waves was published in 1914 by Mason E. Hufford.[1] Over the range of twenty-five apertures, it showed dark-centered diffraction patterns for even numbers of half-period elements and bright-centered patterns for odd numbers of half-period elements. Only by great precision could such a result be obtained. The diffraction box used was 12.3 m long, so that visual observations must have been difficult if at all possible.

The writer has so much admired the experiment that he has tried to simplify it for demonstration with equipment readily at hand and to make the diffraction patterns easily visible to the eye. This has been done for about ten half-period elements. The apertures of a Starrett drill gauge have been used, the diffraction box is shortened to about 3 m, and direct vision of a number of patterns at one time has been accomplished by the use of a double-convex lens of 5 in. diameter and about 14 in. focal length.

In Fig. 1, *S* represents a small sodium vapor

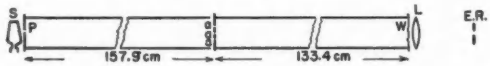

Fig. 1. Vertical section of the diffraction box.

arc, *P* is a pinhole (about 0.4 or 0.5 mm in diameter) in tinfoil, *a a a* are apertures in the drill gauge plate, *W* is a wire or thread across the end of the diffraction box (to fix the attention of the observer's eye upon this plane in space), *L* is the lens and E.R. is an eye ring with an aperture about 1 cm in diameter. The eye ring is mounted on a movable stand and is fixed to accommodate the eye when the point has been found where the eye receives all the light from all of the apertures in the field of the lens.

The drill gauge has 60 finished apertures ranging from 0.04 to about 0.22 in. diameter. The drill gauge plate has a thickness of 2.14 mm. Due to the shape of the gauge plate, only about 15 apertures come into the field of the lens at one time. The lens enables the eye to see bright, virtual, enlarged images of the wire *W* and the diffraction patterns in the plane with the wire. The wire can be moved across the field so that any pattern in the field may be examined.

Fig. 2 is a composite photographic print from seven exposures taken in groups of six (or five) diffraction patterns at one time. The wire and the lens were removed and a process plate put in its place for photographing. In the left and right margins are the numbers of the drill gauge apertures corresponding to the diffraction patterns adjacent to these numbers. The intermediate sizes can be found by counting along the rows. The calculated positions for the first twelve half-period patterns are indicated by darts and by the numbers 1*e*, 2*e*, etc. For example, the calculated aperture for ten half-period elements is almost identical with size 28 in the drill gauge; that for three half-period elements is about one-third size larger than drill size 48, etc.

Fig. 3 is a photograph of patterns produced by rough drill holes in a brass plate of the same thickness as the drill gauge plate. The diffraction pattern at the inner end of the spiral corresponds to drill size 60. The holes were spaced in groups of five, using all drills in order from 60 to 30. A one-by-one comparison of the patterns in Fig. 3 with those in Fig. 2 shows the same features in both sets of patterns for all sizes of drills from 60 to 30. The calculated positions of odd-number half-period elements are indicated by single dots or commas, and those for even-number half-period elements, by double dots or commas, over the span of the first eight half-period elements. The drill holes were made hurriedly and cleaned only by running the twist drills through until the shanks of the drills acted as cleaners in the walls of the holes. This set of crude holes has an advantage over the drill gauge in that the holes are so grouped that all can be seen in one glance when the patterns are viewed through the 5-in. lens.

[1] Phys. Rev. (2) **3**, 241–43 (1914).

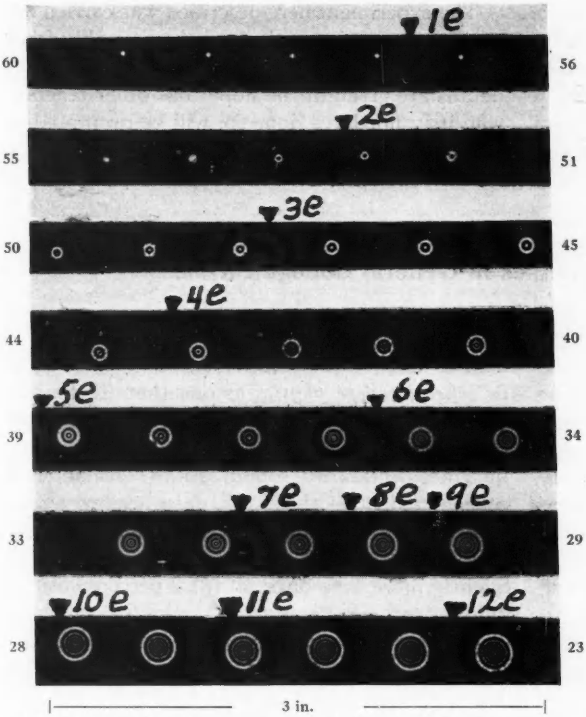

FIG. 2. Composite of seven exposures with the drill gauge, actual size.

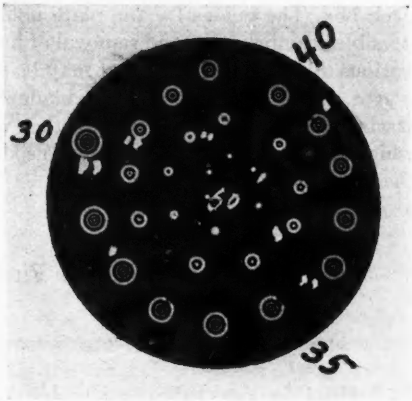

FIG. 3. Diffraction patterns produced by rough drill holes, actual size.

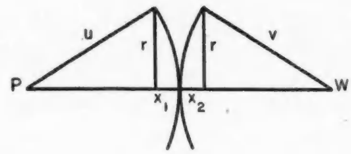

FIG. 4.

The sizes of the various apertures for whole multiples of half-period elements may be found from a consideration of Fig. 4. It will be seen that the extra path traversed by a wave from P to the boundary of a hole of radius r and thence to the point W at the center of a diffraction pattern is the sum of two sagittae, x_1 and x_2. Hence if n is the number of half-period elements and λ is the wave-length,

$$n\lambda/2=x_1+x_2=(r^2/2u)+(r^2/2v), \tag{1}$$

from which

$$r=\surd\, n(uv\lambda/(u+v))^{\frac{1}{2}}. \tag{2}$$

The writer used the manufacturer's data for drill diameters, as stamped in thousandths of an inch on the gauge plate, when placing the calculated positions $1e$, $2e$, etc.

It is interesting to note that up to about twelve half-period element apertures, the patterns made by the drill gauge holes give the appearance of bright centers or of dark centers, apparently favoring the calculated number of half-period elements to which each hole most nearly corresponds.

Photographing the patterns.—With a small Cenco mercury-in-glass arc lamp placed 1 in. from the pinhole at P, and the plate holder at the point W, the first five half-period element-range may be photographed without any filters or spectroscope. Eastman process plates were used with 1 min. of exposure. Above five half-period elements, dissonance between line 4358A and shorter wave-length lines obliterates the centers of the patterns, 4358A being the stronger line. With the mercury arc about 2 in. from the pinhole and with Cambosco filters Nos. 6 and 11 between the arc and the pinhole, 12 to 15 min. exposure photographs the pattern for wave-length 4358A as in row 39–34 of Fig. 2, and as in Fig. 3. The remainder of Fig. 2 was photographed with line 4358A spectroscopically isolated.

The diffraction box used was made of two detached, wooden pipes from a church organ, fitted for holding $3\frac{1}{4}\times4\frac{1}{4}$ in. plate holders in the end of

each box. The guides for the plate holder make possible easy insertion and removal of holders for various diffracting objects that may be placed at *a a a*. A Probak safety razor blade makes a fascinating diffraction pattern, the whole of which can be seen at once when the sodium arc, the lens, and the eye ring are used.

The experiment here described was carried out without design in particulars, the assembly for it being made at random from things at hand. The details are given in the hope that other teachers who may not have done so, will be prompted to use a similar demonstration as a regular feature in the intermediate course in physical optics.

Variability in the First Courses in General College Physics

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THERE appears to be considerable discussion about what should constitute the first course in general college physics. There is reason to believe that much of the confusion and misunderstanding arising from such discussions comes from the failure to recognize the inherent differences in the courses offered. While investigating another problem some rather interesting data were collected which bear directly on this subject.

As part of this larger study[1] it became necessary to obtain data on the first course offered in various institutions. Accordingly, in December, 1934, a printed form was sent out to the institutions on the approved list for 1933–34 of the Association of American Universities. Of the 273 institutions on the list 211, or 77.3 percent, returned usable data. Every state in the union was represented while one institution from Hawaii and one from Canada responded.

Variations in the way the courses were reported made it necessary to define a *first course in general college physics* as one that (*a*) has no college physics prerequisite, (*b*) includes mechanics, heat, light, electricity and magnetism, but not necessarily sound, and (*c*) is allowed college credit. On this basis, data became available for 379 first courses. The number offered by a given department ranged from one to five. Slightly more than one-half (51.2 percent) of the 211 institutions offered two or more first courses. Table I shows the distribution. The institutional grouping used in the first column is that of the Association of American Universities.

The returns indicated that, of the 379 first courses studied, 203 had specific names. Table II lists the titles appearing at least twice. Sixteen titles accounted for 203 courses.

There were 43 different, general textbooks and 7 specialized textbooks reported in use in these courses. Only 16 were reported by more than one institution. There were 32 published laboratory manuals reported but only half were mentioned by more than one institution. The returns showed that locally prepared manuals were used exclusively in 56.8 percent of the institutions.

[1] *Mathematical Requirements for the First Courses in General College Physics*, doctor's thesis, Univ. of Pennsylvania (1936).

TABLE I. *Distribution of the number of first courses offered.*

Institutional Group	No. of First Courses Offered					Total Courses Reported	No. of Institutions	Av. No. of Courses per Institution
	One	Two	Three	Four	Five			
Member universities	4	12	6	4	1	67	27	2.44
Non-member universities	2	2	3	1	0	19	8	2.38
Technological schools	14	4	4	1	1	43	24	1.79
Liberal arts colleges	83	46	19	2	2	250	152	1.64
Total	103	64	32	8	4	379	211	1.80
Percent	48.8	30.3	15.2	3.8	1.9			

TABLE II. *Frequency of the name of the first course.*

General physics	138
Elements of physics / Elementary physics	16
Engineering physics / Physics for engineers	13
Survey of physics	6
Introductory physics	6
College physics	6
Household physics / Physics of the home	5
Premedical physics	4
Principles of physics	2
Other names, appearing once	7
Names lacking, doubtful or simply numbered	176

TABLE III. *Average minutes per week of "nonlaboratory" work.*

Relative Level of Difficulty	Number of First Courses Offered				
	One	Two	Three	Four	Five
A	171±36[1]	150±32	138±31	131±23	82±28
B		189±37	164±26	158±43	166±33
C			202±32	180±30	195± 8
D				244±44	198±24
E					223±23
Average	171±36	170±35	165±30	178±35	173±23

Average for all combined 171 ±33

[1] Average deviation from the mean.

TABLE IV. *Average minutes per week in laboratory.*

Relative Level of Difficulty	Number of First Courses Offered				
	One	Two	Three	Four	Five
A	177±66[1]	123±46	116±42	69±53	78±48
B		184±57	181±50	104±53	114±31
C			190±64	160±25	175±30
D				180±51	145±25
E					223±38
Average	177±66	154±51	162±52	138±46	149±34

Average for all combined 156±51

[1] Average deviation from the mean.

Only 29.4 percent reported exclusive use of published manuals.

In order to reduce the large amount of reported detail to manageable form, a subjective judgment was made of the relative difficulties of the courses for each institution offering two or more first courses. For example, in the case of an institution offering three first courses, each course was carefully considered on the basis of the several factors indicated in the tables and a rating made of its relative difficulty with respect to the other two courses at that institution; the least difficult course was called the *A level* and the most difficult, the *C level*. A representative number of physics departments were asked to check upon these ratings of their courses. The responses showed that the subjective judgment was, at least, 80 percent correct.

The scheduled time allotment per week for recitation, lecture, quiz or any scheduled time other than laboratory is shown in Table III. The table shows two rather interesting points: first, the time allotment increases as the level of difficulty of the course increases; second, the averages for the columns are practically the same. In Table IV is shown the scheduled time allotment for laboratory. With one exception in the fifth column, and a greater variation in the time allotments, this table shows the same general tendency as Table III.

The year in which the first courses are normally taken is shown in Table V. As the difficulty of the course increases the course tends to fall in the sophomore year. Yet it is interesting to note that the percentages for the columns are roughly the same, with the exception of the five-course institutions where the small number of cases may possibly account for the poor agreement.

In answer to the question, "For whom is the course designed?" Table VI shows that 15 curricular groups were mentioned for a total of 634 times. Arts, pre-medicine, engineering, and majors accounted for 81.5 percent of the total mentions.

TABLE V. *Frequency of the year in which the first courses are normally taken.*

Relative Level of Difficulty	Number of First Courses Offered										Total Courses in Level	
	One		Two		Three		Four		Five			
	Fr.	So.	Fr.	So.	Fr.	So.	Fr.	So.	Fr.	So.	Fr.	So.
A	45[1]	57	43	20	23	9	4	4	2	2	117	92
B			19[2]	43	12	20	4	4	1	3	36	70
C					10[3]	22	4[4]	4	1	2	15	28
D							2[5]	6	2	2	4	8
E									0	4	0	4
Total courses	45	57	62	63	45	51	14	18	6	13	172	202
	102		125		96		32		19		374	
Percent	44.5	55.9	49.6	50.4	46.9	53.1	43.8	56.2	31.6	68.4	46.0	54.0

[1] 6 of these courses extend into the sophomore year. [2] 4 extend into sophomore year. [3] 2 extend into sophomore year. [4] 1 extends into sophomore year. [5] 1 extends into sophomore year.

TABLE VI. *Curriculums for which the first courses were designed and the frequency of mention.*

Curriculum	Frequency in percent
Arts	29.0
Pre-medicine	18.5
Engineering	18.0
Majors phys., chem., phys. sci., math.	16.0
Home economics	3.5
Agriculture	1.9
Architecture	1.5
Dentistry	1.3
Education	1.1
Business	0.8
Music	0.6
Veterinary science	0.5
"All"; "and others"	6.5
Omitted	0.8

Table VII, shows the variability in the mathematical prerequisites for 351 first courses. The range extends from no additional mathematics required for registration in the course to calculus corequisite.

Additional data, not shown here, indicate that certain curricular groups were mentioned more frequently in the less difficult levels than in the more difficult levels. The arts group, for example, was mentioned most frequently in the least difficult levels; the engineering group, in the most difficult levels. The premedical group and the majors were most frequently mentioned for the medium-difficult levels.

TABLE VII. *Distribution of the stated mathematical prerequisites.*

Mathematical Prerequisite	No. of First Courses Offered															Total	Per-cent
	One	Two		Three			Four				Five						
	A	*A*	*B*	*A*	*B*	*C*	*A*	*B*	*C*	*D*	*A*	*B*	*C*	*D*	*E*		
None	41	47	9	22	8	3	4	6	1	1	4	4	2	1	0	153	43.5
High school physics	0	C	7	1	3	2	0	1	2	0	0	0	0	0	0	16	4.6
Corequisite, freshman mathematics	7	3	5	0	3	2	1	1	2	1	0	0	1	1	0	27	7.7
Prerequisite, through trigonometry	33	5	21	3	9	8	0	0	2	0	0	0	1	2	2	86	24.5
Prerequisite, through analytics	10	4	13	1	4	5	1	1	4	0	0	0	0	0	0	43	12.3
Corequisite, calculus	5	0	6	0	0	11	0	0	0	2	0	0	0	0	2	26	7.4

Sufficient data have been given to show that there are wide differences among the first courses offered. These differences are due to real needs and should be so recognized. From the evidence presented it would appear that one can no longer speak with accuracy of the first *course* in college physics in a singular sense.

Why the Woman Student Does Not Elect Physics

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THE purpose of this article is: (1) to give the results of a survey which affords a comparison of the enrolments and the numbers of major students in physics, chemistry and biology classes in standard arts colleges for women; (2) to offer a possible explanation as to why the enrolment of women in college physics is lower than that in college chemistry and biology; (3) to give the opinions of the author and others as to the necessity for a change in the physics curriculums for arts students.

Forty-four standard colleges for women, having a total enrolment in 1935–36 of 23,579 students, were asked for data on the enrolment in the first courses and the numbers of major students in physics, chemistry and biology. Thirty-eight of the colleges replied. Thirty-six of these supplied the data requested. References to this survey have been made by Knowlton[1] and by Morrison.[2]

The data acquired are summarized in Tables I and II. They show that: (1) the institution having the largest enrolments in the first courses in physics do not have the largest number of students majoring in this science; (2) the enrolments in the first courses in physics, chemistry and biology are roughly in the ratio of physics, 1, chemistry, 2, and biology, 3; (3) the numbers of the major students in these sciences are in the ratio of physics, 1, chemistry, 6, and biology, 10.

It is evident that the interest of women students in the subject matter of physics is far less than that in chemistry and biology. There are definite causes which bring about this condition. Three have been suggested to Knowlton[1] by nonscience students:

"Chemistry and biology have more obvious applications to life, to the planning of menus and the care of babies.

"Chemistry in particular is more colorful. The laboratory work is more attractive because something unexpected is likely to happen at any instant.

"Most students have a greater feeling that they have understood and, to some degree, mastered the material and theories of chemistry and biology than is true in physics. In chemistry everything centers about the atomic theory, and the same procedures repeat themselves until they become familiar, whereas in physics one is continually going to something new that seems to bear little relationship to what has gone before. There is less feeling of accomplishment."

[1] Am. Phys. Teacher **4**, 71 (1936).
[2] Am. Phys. Teacher **4**, 117 (1936).

Adding to these possible causes, I suggest four others. The first is the use of mathematics. There is no getting around the fact that physics makes use of more mathematics than chemistry, while biology may be said to use none at all in the first general course. As much as we dislike to admit it, this is one reason for the election of biology in preference to either chemistry or physics.

A second cause has been suggested to me by a group of secondary school teachers. These teachers claim that the majority of the smaller secondary schools not offering physics do not offer the science because of the initial cost of equipment. There is a rather large number of these schools. If this is generally true, then a large number of students enter college without having had the opportunity of becoming acquainted with the subject matter of physics. This, however, may be an advantage to college physics teachers, if the next cause we shall consider can be justified. This cause has been suggested by industrial friends who have become so interested in the idea that they are supplying the necessary funds for a survey which will determine the correctness or incorrectness of the suggestion; namely, a practice in secondary schools of assigning the job of physics instruction to teachers who have not prepared themselves to teach physics.

While I have no facts to substantiate the statement, I venture the opinion that in the past a large percentage of our high school classes in physics have been taught by such teachers. If the result of the survey should show that this

TABLE I. *Science enrolments in 36 colleges for women**

College No.	1935–36 enrolment	Percentage enrolment in first courses		
		Biology	Chem.	Physics
1	1527	20.9	7.4	5.3
2	403	13.4	19.3	1.9
3	424	20.5	17.9	7.3
4	404	9.1	16.3	5.4
5	1528	26.0	10.0	18.4
6	421	29.9	12.1	6.4
7	1200	6.7	6.7	5.0
8	630	27.6	21.3	15.5
9	993	17.3	7.6	5.3
10	643	22.8	5.9	5.6
11	503	13.5	6.0	4.1
12	336	13.7	3.3	1.5
13	304	18.7	11.8	2.6
14	1236	—	3.4	0.65
15	1301	15.9	11.9	0.38
16	201	30.8	13.4	1.0
17	310	32.2	10.3	9.3
18	1936	—	5.06	2.7
19	308	18.1	10.7	1.3
20	1494	20.1	3.4	4.08
21	1000	6.0	1.5	2.8
22	238	32.3	31.9	7.1
23	452	23.9	8.8	3.7
24	270	17.0	9.6	7.0
25	215	25.1	15.3	1.8
26	330	13.0	14.5	2.1
27	546	19.6	12.8	3.6
28	803	6.3	11.9	2.2
29	551	5.4	3.8	1.27
30	315	14.9	13.6	5.0
31	273	17.2	30.8	5.5
32	694	29.1	10.4	0.57
33	280	24.2	2.5	25.7
34	987	23.4	7.8	4.35
35	202	24.2	10.4	1.4
36	321	30.5	14.3	5.3
Average		16.5	9.18	5.09
actual enrolment	23,579	3,908	2,165	1,202

* Colleges No. 14 and 28 offered survey courses in natural sciences in which the enrolments were 17.4 and 16.5 percent, respectively.

TABLE II. *Number of women majoring in the sciences. "N.O." means "not offered;" (—) means no data were supplied.*

College No.	Biology		Chemistry		Physics	
	'34–35	'35–36	'34–35	'35–36	'34–35	'35–36
1	26	22	14	12	1	0
2	23	19	5	3	0	0
3	21	25	11	13	1	2
4	26	19	15	10	1	0
5	7	8	7	7	1	2
6	3	2	2	1	—	—
7	60	53	40	34	14	12
8	10	13	18	23	0	0
9	27	36	39	37	4	2
10	19	15	20	12	5	6
11	11	12	9	11	2	0
12	11	6	3	1	—	—
13	7	3	1	1	N.O.	N.O.
14	33	11	16	23	0	0
15	38	36	6	7	0	0
16	3	2	1	1	N.O.	N.O.
17	10	5	3	1	3	2
18	—	—	11	11	6	5
19	N.O.	N.O.	4	4	N.O.	N.O.
20	31	26	17	12	0	2
21	32	31	24	14	5	7
22	4	8	0	1	0	0
23	13	10	8	4	0	0
24	3	2	8	0	0	0
25	2	1	1	1	0	0
26	3	3	4	5	1	1
27	2	3	3	6	N.O.	N.O.
28	18	21	12	6	0	0
29	18	24	12	14	1	0
30	2	2	3	5	0	0
31	—	7	—	3	—	0
32	11	27	1	0	0	0
33	23	14	2	3	2	5
34	58	49	29	28	5	2
35	10	16	1	2	0	0
36	2	6	4	10	3	2
	567	537	354	326	55	50

claim is justified, then it would appear that a positive dislike for physics may be acquired by the students before they enter college. There are those who point to the fact that since more women do not go beyond the first course in college physics there must be something wrong with the college physics teacher or the method of teaching physics to college women. This no doubt is true.

Another cause for the small enrolment in physics has come from conclusions reached after a number of years spent in an attempt to teach physics to women college students; it has to do with the content and presentation of the first course in physics. I am not advocating an "easy" course, but an interesting one. I do not suspect that any of us would advocate that the subject matter and the method of approach be changed so as to make a so-called "crip" course. The training and the environment of women are usually such that they do not become mechanically minded, and consequently do not find machines and physical principles easy to understand. They are interested, however, in knowing why things work as they do. We will certainly agree that women enjoy, perhaps to a greater degree then men, the comforts and pleasures that come through the advancement of physics. Surely women are as capable as men of deriving the same cultural value from physics as from any other non-science or arts subjects.

Some teachers may be inclined to agree with a university professor who has written me that the problem of women in physics has always been and will probably always be as it is, and there is nothing much that we can do about it. I disagree with my colleague. Physics should be made so attractive to women, or to any other students, as to cause them to recognize the same enjoyment from it as from any other subject taught in the schools and colleges. While it is true that at present there are not many opportunities in industry or in colleges for the employment of women who have majored in physics, it is my opinion that women should take physics as a part of their cultural program, since we are living in a scientific civilization and so much of our equipment and surroundings of life are based upon physical principles. The paucity of outstanding women physicists should further justify our claim that women should study physics. Why should we not have more women physicists?

That women are not electing courses in high school and college physics is a fact. As to the causes, we may be in error. We who teach women are deeply interested in ascertaining the causes. In Virginia we plan to consider the problem at a conference of representative teachers of college physics to women, to be held in the spring in conjunction with the Virginia Academy of Science meeting. Ten of the twelve college departments invited to participate in the conference have approved of the plan and will send representatives.

In considering further the status of the curriculums for arts students, particularly women, let us examine the opinions of others who are qualified to speak. The director of an organization interested in the placement of college trained women in industry writes:

> "Thank you . . . for . . . the material on the registration of women in physics classes. This is a subject in which [we have] been most definitely interested for some time. We have felt a very real need for a comprehensive study of opportunities for women in physics and chemistry. There are, for example, certain developments in the equipment field which would seem to indicate opportunities for women trained in home economics and well equipped in physics.
>
> ". . . Our interest in this problem . . . has been growing as we are working toward the completion of a study of business openings for home economics trained women in industry. There seem to be definite possibilities for the employment of such women in work connected with lighting and with household equipment. However, very few women with home economics education have the requisite training in physics so that they have not been able to obtain the really fundamental jobs in this field. The solution of the problem would seem to require the cooperation of persons interested in occupations, teachers of physics and teachers of home economics."

Another statement of interest comes from a former teacher of physics who is now the Director of Higher Education in a State Department of Education:

> ". . . It is true that at this moment chemistry and biology have the edge so far as State Board regulations are concerned. Such advantages as they enjoy, though, have come largely because physics failed to measure up to its opportunities when it had a chance. Physics, like Latin, is about to be destroyed by its own advocates. . . ."

The opinions of some of our colleagues should

be given. A woman professor of physics in a well-known woman's college writes:

"... I am somewhat opposed to changing the nature of the first course in physics, but I do feel that we can revise it, cutting out some parts which do not strictly pertain to the modern applications, and give more time to recent developments. This problem ... does not pertain solely to the women's colleges. All of the liberal arts colleges where physics is an elective course need to carefully study their present course with a view of changing the emphasis but not in making the course less difficult. As to women students majoring in physics with the present situation in industry and colleges, it seems to me that women will find more opportunity in the field of biophysics than in some other applications. ..."

A professor in an outstanding college for men gives his opinion as follows:

"I was not at all surprised at the relative popularity of the three branches of science compared. I was, also, not surprised to know the small percentage of girls studying physics, in light of the fact that of the graduates (men and women) of all colleges in America less than five percent study physics. Biology, I noticed, was by far the most popular of the sciences (with women) at Johns Hopkins, University of Chicago, Cornell and Columbia. That surprised me. I thought it very strange on first thought, especially considering a woman's usual abhorrence of everything connected with dissecting. However, I decided the explanation must be that women are fundamentally interested in life—therefore the study of biology. I agree with you that physics should be made more attractive to women."

A university professor of physics writes:

"[Your findings show that] the situation is even more pronounced than I had imagined, though I know of course that even in men's schools physics trails rather far behind biology and chemistry. You are certainly right in feeling that we should try to do something about it, though just what is a big question.

"Many men, and I dare say even more women, object to physics because we generally want them to do some problem work and use some mathematics. Apparently mathematics is one of our barriers. On the other hand, I dare say the whole subject matter might be reworked or presented in more alluring fashion. ... However, further experiments will doubtless be made, and I hope the Association of Physics Teachers will help us find the solution. I wish I could make a ... suggestion, but am afraid I cannot. However, I can at least sympathize, for I have been trying to work up a second year of physics for undergraduates and have tried several books and several ways and none of them is just right."

From the Director of the Division of Surveys and Field Studies in a teachers college we have these words:

"I think you are quite right in assuming that the materials included in physics should be revised. ... I believe physics has a great deal to contribute to the general education of both men and women students. ..."

We could quote from others, but it is perhaps not necessary. There is a very definite concern—one that is growing—about the matter of the small enrolment in physics classes. An attempt to change the content of the course taught women or non-science students, or an attempt to correct other causes which may be responsible for the condition, needs the careful study and the full support of all who are interested in physics curriculums for liberal arts students.

Photography in the Physics Curriculum

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A RECENT survey of the curriculums in physics of 50 colleges and universities showed that only 10 of these include photography among their regular courses of study. This is a surprisingly small number when we consider the claims of photography as a subject for serious study. The question arises as to why more interest has not been shown in adapting the subject to work of college caliber.

One possible explanation may be the expense involved in providing darkroom laboratories for large groups of students, and the additional work required in purchasing and distributing the necessary supplies. Most departments, however, are already equipped with one or more darkrooms and usually there are other rooms with sinks and running water which could be easily darkened by movable curtains made from plywood or even heavy black cloth. The walls need not be blackened; in fact a light colored wall may have advantages. The writer finds that three or four students may work comfortably in a dark-

room, if it is properly arranged. Hence, if three such rooms were available for, say, four different periods a week, a class of 40 to 50 students could be accommodated. The handling of supplies if properly organized need not require any more time than that for a laboratory course in general chemistry, and could be detailed to a student assistant.

No doubt another factor in the failure to appreciate the possibilities of photography as a college subject, has been the popularizing of the hand camera by commercial photographers. Their slogan is, "You press the button and we'll do the rest," which of course does not require a high order of intelligence. The facts are, however, that photography can be made of ample difficulty for college students and there is plenty of text and laboratory material available for use.

One must appreciate the tremendous improvements in cameras and photographic processes which are being made and the ever widening use of photography in many different fields. The motion picture industry, for example, affords employment for thousands, of whom undoubtedly many do not possess adequate fundamental training. What are we in our physics courses providing in the way of basic instruction in the field of motion picture photography? The introduction of high grade cameras, built with watch-like precision, using small negatives at a minimum of processing expense, yet capable of producing results comparable with those obtained with bulky and unwieldy equipment, is stimulating widespread interest in photography. Our publications, both scientific and otherwise, are making increased use of various photographic processes. In fact some are devoting more space to pictures than to reading matter. In all fields of research the value of photography has long been recognized. Yet what training do we provide for research students? Do they receive adequate instruction in the theory of density, tone reproduction, control of contrast, the use of the camera, and the properties of developers, or do they pick up what little they can through unsupervised experimentation, thus too often acquiring faulty technics? A casual observation of lantern slides and prints presented at scientific meetings leads one to believe that they have been made in great haste or else without benefit of a satisfactory technic. Recently the writer asked a class of forty students taking general physics, how many of them had ever taken and complteely processed a photograph? Only sixteen had done so, or about 40 percent.

The experience of the writer covering a period of ten years is that there is perhaps no subject in physical science which gives the student a greater appreciation of science than a study of the physical and chemical bases underlying photography. Unusual opportunity is afforded for dealing with the properties of light rays and geometrical optics. Years of study could be devoted to the mastery of the uses of the many light sensitive materials now available. What more fascinating study is there than that of color and the brightness of objects, and yet for lack of understanding how little do we appreciate the colorful panorama which daily passes before our eyes? The process of development, involving both chemistry and physics, cannot fail to grip student interest. Pleasures in teaching still remain, and one of them is to hear the exclamations of surprise and wonder as the student watches for the first time by the dim safelight "the miracle" of an image forming on a piece of exposed printing paper in the developing bath. For the advanced students, research problems concerning various phases of development still await solution.

With the shorter working day and the ensuing problem of utilizing leisure time, the pursuit of a "hobby" as a relaxation from serious work is being highly recommended. Many students, majoring in other fields, would find a laboratory course in photography an excellent preparation for a life-long pursuit of the subject as a "hobby."

By the very nature of the subject it seems logical that the burden of providing enlarged facilities for the study of photography should rest with physics departments. By so doing we may to some extent at least open a new field of employment for physics students, provide training for those using photography as a tool in research, and make it possible for the amateur to pursue photography as a "hobby" in a truly scientific manner.

NOTES ON APPARATUS, EXPERIMENTS AND DEMONSTRATIONS

Note on Physics Museums

I WAS much interested in the description of the University of Wisconsin Physical Museum, which appeared in the September, 1936, issue. My chief regret was the brevity of the article, causing the omission of a complete list and of the details of some of the demonstrations. Possibly Professor Ingersoll will contribute a complete list. Others may have worked on a similar enterprise and have ideas to contribute.

Something which I first saw in the Sloane Physics Laboratory at Yale never fails to catch the eye: a "piece" of asphalt or tar, the material used in roofing, flowing slowly down an incline arranged with obstructing cleats, rather like a fish ladder.

We had last year an automatic match extinguisher. A candle-end is in front of a small opening in a cardboard box concealing a photoelectric cell, an ordinary three-electrode tube and one of the gas filled, thyratron type, resistance coupled, operating a relay and a small electric fan. When a match is brought to light the candle, the fan starts and blows it out.

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A Convenient Mercury-Vapor Lamp

IN a student spectroscopic laboratory one needs a source of light that gives a reasonable number of lines, is easy to set up, and does not sputter salt over the laboratory. A mercury-vapor lamp is such a source, but special lamps designed for the laboratory are expensive and the commercial lamps are large and inconvenient.

In recent years the hot mercury-vapor tube rectifier has become standard and the price has been reduced so that an 866-tube can be bought for less than two dollars. This tube and all the apparatus necessary to use with it can be mounted on a base 6 in. square. A few feet of lamp cord with a plug terminal connects this to an a.c. outlet.

The tube filament operates at 2.5 v and takes 5 amp. The plate potential can be anything from 15 to 5000 v. The rated maximum plate current is 0.5 amp. The filament is connected to a filament transformer of the proper rating. The plate is connected in a series with a 200-ohm 75-w resistor to one side of the 110-v coil of the transformer and the other side of the coil is connected to the filament of the tube. When the tube is so mounted, one has a small portable mercury-vapor lamp which can be used any place in the laboratory. The bulb of the 866 tube is egg-shaped, 10 cm long and 6 cm wide, making the area of the lamp perhaps 45 cm^2.

When the load-resistor is adjusted as indicated and the plate current is 0.3 amp., the intensity is sufficient for all laboratory use. If the tube is overloaded, with the plate current 1 amp., the intensity is equal to that given by the best mercury-vapor lamps. The filament is heated to a dull red temperature, making the continuous spectrum from the filament practically negligible.

If the tube, transformer, resistor, etc., are selected from the catalog of a radio supply house the total cost will be less than five dollars.

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A Simple Thermocouple for Demonstrating the Properties of Thermal Radiation

FOR demonstrating the absorption, emission, reflection, etc., of thermal radiation a sensitive thermopile and a good galvanometer are required. The construction of a thermopile with fine wires, soldered junctions, and blackened receivers is a matter requiring some technical skill. However, a simple thermocouple can be made in the following way in a short time, and for most purposes this instrument is entirely satisfactory.

A thick-walled brass tube about 3 cm long and 2 cm in diameter has an ebonite plug fitted into one end. Two brass machine screws pass through this plug and each is fitted with two nuts so that it can serve as a binding post. Short pieces of copper and constantan wire are soldered to the heads of these screws. These wires may be 1 cm long or less, and are preferably of small diameter, say No. 36. Each wire is now immersed for about half its length in a mixture of equal volumes of nitric and sulphuric acid, and closely watched until the wire has become fine and hair-like. After rinsing off the acid the wires are bent till their two sharp tips just touch. A good hand lens is needed in making this adjustment. The tips are welded together by discharging a condenser across the junction. A 40-v B battery and a 1-μf condenser are used, but it is desirable to make an initial discharge through a series resistance of about 10 ohms if the wires are very fine.[1] A weld made in this way is easily jarred loose, but if a small amount of Aquadag[2] is put on the junction and allowed to dry the mechanical strength is much increased. The resistance of the junction may be 4 or 5 ohms, and should be checked in order to test the efficacy of the weld.

The receiver for the radiation is made from aluminum foil coated with Aquadag. In coating the foil one end is held down with the forceps against a piece of paper and the Aquadag is applied by means of a small glass rod. It is necessary to use thick Aquadag and to stroke quickly outward and away from the forceps in order to avoid difficulty with surface tension effects. When the Aquadag is dry the foil is quite easily handled and may be trimmed to the proper size—about 0.7×0.7 cm—with a safety razor blade. At the center of the uncoated side of the foil is placed a small spot of Aquadag. The foil is then held in the forceps close to the junction, fresh Aquadag put on

the junction, and the foil immediately applied, contact being made at the center spot. This method of mounting the receiver requires little skill and seems to give very satisfactory results.

The ebonite plug is now inserted in the brass tube and may be mounted on a suitable stand. A stopper in the open end protects the thermocouple when it is not in use. With a galvanometer of low resistance and high sensitivity a thermocouple made as described will detect the radiation from the hand at a distance of about 1 m, and it does not have an unduly large time-lag.

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[1] C. H. Cartwright, R. S. I. **3**, 73 (1932).
[2] Colloidal graphite in water, Acheson Colloids Corporation, Port Huron, Michigan.

Measurement of e/m for Thermoelectrons

MOST methods of measuring e/m for electrons require equipment that is too expensive for the average small college laboratory. For example, this would be true of such outstanding methods as those of J. J. Thomson, Lenard, and Bucherer. As a result many college students know the important ratio of e/m only as a textbook quantity. We should like to suggest that the magnetron method originally developed by Hull[1] and later adapted to laboratory use by Harnwell and Livingood[2] not only gives accurate results, but may be used with apparatus found in practically any laboratory.

In the magnetron method (Fig. 1) a vacuum tube T with a cylindrical plate and a straight filament mounted along the axis of the cylinder is located at the center of a long solenoid C carrying current. With the tube in operation, the magnetic field of the solenoid may be adjusted by means of the bank of lamps L until the electrons are prevented from flowing to the plate. When this condition prevails, the value of e/m may be found if we know the plate voltage V, magnetic field strength H in the coil, and radius b of the cylindrical plate.

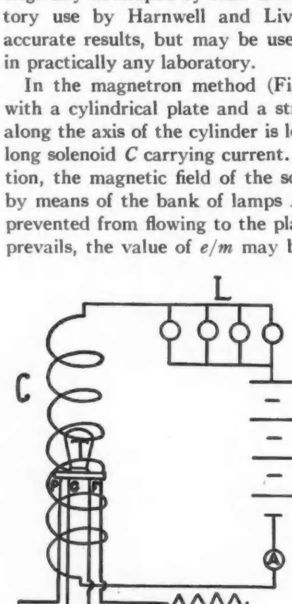

FIG. 1. Diagram of apparatus.

TABLE I.

I (amp.)	H (e.m.u.)	V (volts)	e/m (e.m.u./g)
4.90	37.60	11.30	1.77×10^7
7.31	56.0	25.0	1.77
9.0	69.0	38.15	1.78
10.75	82.4	53.5	1.75
11.6	88.9	63	1.77
12.8	98.1	75.5	1.74
14.0	107.2	90.5	1.75
15.8	121.0	117.5	1.78
		Mean value	1.76×10^7

The coil C consists of 256 turns of No. 14 insulated copper wire. Its length should be more than seven times its diameter. The ux22 radio tube T is mounted on a stand so that the plate is at the center of the coil. Either B batteries or a d.c. line may be used as the source of plate voltage B. The connections and location of meters are shown in Fig. 1. The plate voltage is read at V and the solenoid current necessary to reduce the plate current MA to zero is read at A. The grid is maintained at a sufficiently high positive potential to insure an even flow of plate current. This grid potential does not affect the calculation of e/m.

It should be noted here that the degree of accuracy of the magnetron method depends largely upon obtaining a dependable value of the solenoidal field H. To determine this accurately, the component of the earth's field parallel to the axis of the coil should be included. In the present experiment the coil was mounted vertically and the plate-current meter was read through a magnifying glass. No difference in readings could be obtained with the coil tipped at any angle to the earth's field. Another source of error is the fact that commercial radio tubes (ux22) seldom have a perfectly cylindrical plate with a straight filament exactly along the axis.

Harnwell and Livingood[2] show that when the field strength H is just sufficient to prevent the flow of electrons from filament to plate the value of e/m in e.m.u. per gram is given by the expression

$$e/m=(8V/b^2H^2)\frac{1}{(1-a^2/b^2)^2},$$

where a is the radius of the filament and b is the radius of the cylindrical plate. The field at the center of the solenoid is calculated from the expression $H=4\pi nI/10L$, where I is the current in amperes and n/L is the number of turns per unit length.

For fine filaments the ratio of a^2/b^2 may be neglected and there remains the simple formula $e/m=8V/b^2H^2$. Table I shows eight typical results obtained by this method, for a case where n/L was 256/42 and b was 0.60 cm. Calculations were made with a slide rule.

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[1] Phys. Rev. **18**, 31 (1921).
[2] *Experimental Atomic Physics* (McGraw-Hill, 1933), pp. 118, 124.

DISCUSSION AND CORRESPONDENCE

Problems in Physics Textbooks

At the request of a representative of a publishing house a suggestion is offered in the interest of better problems in textbooks of general physics—problems that illustrate principles more adequately, that progress in difficulty, that stimulate and challenge, that are expressed in clear concise English, and are accompanied by correct answers, when answers are published. Some textbooks now in use, while otherwise well written, contain problems that could be improved.

It is proposed that those who take the pains to write good problems with no thought of publishing them, pool their product for the use of writers of textbooks who care to use them. The proposal might be put into effect in various ways:

(1) An author who is preparing a manuscript might ask for problems in a letter published in *The American Physics Teacher;* such a request would imply no obligation to use any problem offered, but a problem accepted and published could bear the contributor's name.

(2) A publishing house might establish a catalog of problems, invite contributions to it, and place it at the disposal of any writer who submits a manuscript.

(3) The Association of Physics Teachers might establish a catalog of problems for the use of any textbook writer; it would be understood that problems selected from such a catalog could not be copyrighted.

A type of problem that is too conspicuous by its absence from textbooks is the one that calls for "rigorous thinking without arithmetic," as it has been described by D. L. Webster ("The Physics of Flight," J. Frank. Inst. May, 1920). It is a type of semi-quantitative, physical problem that one has to solve many times daily in real life. If a supply of good problems of this type were available some of them might get into the textbooks.

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The Mass of Energy

It is not generally recognized that the conception of mass as an attribute of energy is easily derived from the classical electromagnetic theory[1] and that the theory of relativity need not be used to deduce the expressions $m=\epsilon/c^2$ and $m=m_0/(1-v^2/c^2)^{\frac{1}{2}}$.

The force per unit volume of a conductor carrying a current in a magnetic field **H** is given by the vector product $\mathbf{u}\times\mathbf{H}$, where **u** is the current density. This force is capable of imparting momentum to the conductor. In the absence of a conductor or any other matter there is a displacement current of density $(1/4\pi c)\partial\mathbf{E}/\partial t$ e.m.u. The force upon a unit volume of the field is then given by $(1/4\pi c)(\partial\mathbf{E}/\partial t)\times\mathbf{H}$. This is due to the interaction between the magnetic effect of the displacement current and the field **H**. Furthermore, the variation of the field **H** gives rise to an electric force which interacts with the electric field **E**. The symmetry of the field equations suggests that we take $-(1/4\pi c)(\partial\mathbf{H}/\partial t)\times\mathbf{E}$ as the component of this force upon unit volume. Interchanging the factors in the vector product, we have for this component, $(1/4\pi c)\mathbf{E}\times(\partial\mathbf{H}/\partial t)$.

The total force per unit volume tending to impart momentum to the field is therefore

$$\mathbf{F}=\frac{1}{4\pi c}\frac{\partial}{\partial t}[\mathbf{E}\times\mathbf{H}]=\frac{\partial\mathbf{G}}{\partial t},\quad \text{where}\quad \mathbf{G},\quad \text{or}\quad \frac{[\mathbf{E}\times\mathbf{H}]}{4\pi c},$$

is called the momentum per unit volume of the field since its time rate of change is the force per unit volume.

Poynting showed that the field equations combined with the law of conservation of energy give the equation $(\partial\epsilon/\partial t)+\text{div }\mathbf{R}=0$, where ϵ is the energy density and $\mathbf{R}=c/4\pi[\mathbf{E}\times\mathbf{H}]$ is the energy-flux-density. The usual continuity equation for any fluid entity is $(\partial\rho/\partial t)+\text{div }(\rho\mathbf{v})=0$. We may therefore call **R** the energy-current-density, or $\epsilon\mathbf{v}$, where **v** is the velocity of the energy. Hence $\mathbf{G}=\mathbf{R}/c^2=(\epsilon/c^2)\mathbf{v}=m\mathbf{v}$ where m is the mass of the energy. Thus $m=\epsilon/c^2$.

Assume that for a mass of any kind, $G=(\epsilon/c^2)v$. If a force f acts on it in the direction of motion and there is no loss of energy, then $f=m(dv/dt)+v(dm/dt)$ and $f\,dx=d\epsilon=mv\,dv+v^2\,dm=c^2\,dm$. Separating the variables, we get

$$\int_{m_0}^{m}\frac{dm}{m}=\int_0^v\frac{vdv}{(c^2-v^2)},$$

where m_0 is the value of m when $v=0$. Thus

$$m=m_0/(1-v^2/c^2)^{\frac{1}{2}}.$$

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[1] See, for example, J. Frenkel, *Lehrbuch der Electrodynamik*, pp. 216–217; H. A. Wilson, *Modern Physics*, pp. 8–10.

The Motion of a Weight With Attached Rope

In an article in a recent issue [W. W. Sleator, Am. Phys. Teacher **4**, 143 (1936)] the following statement appears:

> "Eq. (2) may be written
>
> $$dz/(C-8\rho g z^{\frac{3}{2}}/3)^{\frac{1}{2}}=dt, \qquad (4)$$
>
> and $\int dz/(C-az^{\frac{3}{2}})^{\frac{1}{2}}$ is an elliptic integral and accordingly not to be evaluated in terms of ordinary functions. Moreover, it is not readily reducible to one of the standard forms. Various transformations have been carried out, but no integrable form has appeared. This impasse in the solution of so natural and simple a problem will strike the amateur mathematician as incongruous."

But, if the usual classification of all elliptic integrals into three species is to mean anything, it must be demonstrable that *any* integral of a specified type can be reduced to a combination of the three standard forms. Such a demonstration consists only of showing, in general terms, exactly

how the reduction is made. We have therefore only to look up a proof of this theorem and follow it through.[1] If this be done, the results are as follows.

First of all, obvious changes of scale alter our expression to $\int du/\sqrt{(1-u^{3/2})}$. Set $u^{1/2}=v$, so getting $2\int vdv/\sqrt{(1-v^3)}$. The quantity under the radical is changed to a quartic by the transformation $v=1-w^2$. This quartic has only even powers of w and is factorable in the form $(w^2-\alpha)(w^2-\bar{\alpha})$, where α, $\bar{\alpha}$ are the roots of $x^2-3x+3=0$. Now it is plain that a transformation $w/\sqrt{\alpha}=x$ will place the integral in nearly final form. In fact, one finds

$$-\frac{4}{\sqrt{\bar{\alpha}}}\int\frac{(1-\alpha x^2)dx}{\sqrt{(1-x^2)(1-\alpha x^2/\bar{\alpha})}}. \tag{1}$$

Since this is a sum of Legendre's integrals I and II, the reduction is accomplished.

However, α and $\bar{\alpha}$ are complex and it will also be found that the limits are complex, so the integrals cannot be found in tables. But by the use of the theta functions the integrals may be computed by means of series that converge with rapidity although the arithmetical work with complex numbers is a little slow.

Few physics students will understand these methods, however, and so for pedagogic reasons it is worth while to find a method of evaluation that is elementary. For example, in the paper cited, an attempt is made by expanding the integrand of

$$\int du/\sqrt{(1-u^{3/2})}$$

(actually the integral was first transformed but the principles involved are unchanged) and integrating term by term. But, because of the singularity at $v=1$, the series for the integrand does not converge there at all and so the integrated series will converge only very slowly if one limit is near $v=1$. In fact, $v=1$ is an important case and the author of the paper in question finds on trying to sum his series there that "the series, though by test convergent, converges so slowly that, after summing twenty terms or more, one has no idea how near he may be to the actual definite time necessary for the block to come to rest."

Since the poor convergence is caused by $(1-v^3)^{-1/2}$ becoming infinite like $(1-v)^{-1/2}$ at $v=1$, it is obviously suggested that in this region we change variables so as to expand about $v=1$. Thus if both limits are near $v=1$, we use such a series; if both are near $v=0$ we use a series about $v=0$; and if one limit is near $v=0$ and the other near $v=1$, we use both types of series. As this last is the most complicated case we will give the results for it. We have $\int_a^b=\int_0^1-\int_0^a-\int_b^1$ and, by the conditions of the problem, $0<a<b<1$. The second integral is obtained by a series about $v=0$, the third by one about $v=1$, and the first by using one series from 0 to some midpoint and the other from there to 1. The result is easily found:

$$\int_a^b\frac{ydy}{\sqrt{(1-y^3)}}=0.862-\frac{a^2}{2}\left(1+\frac{a^3}{5}+\frac{3a^6}{32}+\frac{5a^9}{88}\cdots\right)$$
$$-\frac{2}{\sqrt{3}}\sqrt{(1-b)}\left(1-\frac{1}{6}(1-b)-\frac{7}{120}(1-b)^2-\frac{1}{48}(1-b)^3\cdots\right).$$

Both series converge rapidly and the computation is further simplified by the fact that for given initial conditions a is constant. In the worst possible case ($a\sim b\sim 0.7$) the third term of each series is less than 0.006 and, carrying four terms (counting the ones), gives four-figure accuracy.

Finally it may be of some interest to investigate more quantitatively the convergence when the series about zero is used out to $v=1$. By considering the transformed form of the integral as used in the paper cited, it is readily found that the typical term in the integrated series is

$$\frac{3}{(3n+4)}\,\frac{1\cdot 3\cdots 2n-1}{2\cdot 4\cdots 2n}.$$

Now for large n the second fraction varies like $1/\sqrt{n}$ and, in fact, is very approximately equal to $1/\sqrt{(\pi(n+\frac{1}{4}))}$. Thus successive terms decrease like $1/n^{3/2}$ and, by integration, the error made by stopping at n terms is of order $1/n^{1/2}$. Thus, to get 1 percent accuracy, 10^4 terms would be needed and the quoted results for 20 terms are not surprising.

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[1] See, for example, Pierpont, *Functions of a Complex Variable*, Chap. XI, p. 383.

A Simple Theorem on the Slide Rule

It is well known that the percentage error of a setting on a logarithmic scale is the same throughout its length, but that the percentage error of a linear measurement is directly proportional to the length measured. The question naturally arises, then, as to what length slide rule is required to compute the result of any given linear measurement? If it be assumed that the experimenter can set the slide rule with the same precision as he obtained in his linear measurement—say to 0.01 in.—it turns out that a 2-ft. slide rule is needed for a 10-in. length. The total length of the slide-rule scale must be $\log_e 10$ times the measured length. In other words, to obtain the same percentage error in calculation as in direct measurement, other things being equal, the length of the slide rule between the scale marks *1* and *2.72* must equal the length measured. The proof is left to the reader or to one of his able students.

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The history of science is the real history of mankind.—EMIL DUBOIS-REYMOND.

Reports of Committees of the American Association of Physics Teachers

The Committee on a Professional Examination in Physics

It is recommended that an annual examination be set at the baccalaureate level, to be known as the *Senior Examination in Physics of the American Association of Physics Teachers and the American Institute of Physics.*

1. *Administration.* The organization and administration of the examination should be in the hands of a central committee appointed by the president of the Association and cooperating with the Institute of Physics. A central office should be designated by the committee and approved by the executive council of the Association.

2. *Character of the examination.* For the first year, examinations should be given in seven divisions as follows: general physics, mechanics, heat, sound, electricity and magnetism, light, and modern physics. Other divisions, such as general mathematics, industrial physics, electronics, etc., could be added later. The time required for each division examination is to be set by the central committee but should not exceed two hours. Each examination should aim to find out how well a student has mastered the basic fundamentals in an actual problem situation. Any examination technic may be used at the discretion of the committee which formulates the examination.

3. *Formulating the examination.* The examination for each division should be formulated by a subcommittee appointed by the central committee which will submit its examination to the central committee not later than December 1. It is assumed that any American physicist is eligible for appointment to a subcommittee. The central committee working with the Institute of Physics would print and distribute the examinations.

4. *Time and place.* The examinations should be given over a two-day period about January 15 of each year so as to have the results available for use in making spring appointments for the next college year. Industrial groups could use the results for summer appointments. The dates and places for the examinations should be determined by the central committee. Examination centers must be so located as to be reasonably accessible to all candidates. Each center should be in charge of a local examiner appointed by the central committee. A fee determined by the central committee should be charged each individual writing these examinations.

5. *Grading.* The written examination papers should be returned to the central office for distribution to graders. The papers should be graded one question at a time, with all answers to a given question in a given division graded by a single grader. The grades should be reported to the central office not later than four weeks after the examinations are given.

6. *Reporting grades.* The central office should make a frequency distribution of the examination results in each division and report to each individual his standing in each division examination taken in terms of both percentiles and a grade based on a perfect score of 100. Permanent confidential records should be kept in the central office and a copy of the record for any individual released only at the request of that individual. Each person taking the examination should be assigned a number and all of his papers identified only by this number.

It is further recommended that the executive committee of the Association, through its representation in the American Institute of Physics, ask the Institute for cooperation in initiating this program.

H. A. Barton, A. W. Hull, D. Roller,
D. L. Webster, C. J. Lapp, *Chairman*

The Committee on the Training of Physicists for Industry

The American Institute of Physics has been taking a series of steps looking towards a better understanding and improvement of the situation regarding the use in the industries of men trained as physicists. This grew out of a feeling that while we have greatly enhanced our national capacity to contribute to the world's knowledge of fundamental physics, we have not attained a comparable capacity to apply the science. As a result the Institute and the Division of Physical Sciences of the National Research Council held a joint conference in December, 1934, at New York, in which the discussions centered around the following items: (1) Assuming that there is a distinct, important, and expanding field for applied physics over and above that now occupied by the several branches of engineering, how can we develop that field? (2) In what ways can the profession cooperate with industries to increase the value to the latter of research work in applied physics? (3) How can we improve the training of men for such work? (4) How can the conference best initiate its recommendations?

The Conference recommended the formation of a committee to cooperate with other agencies and to advise the Institute on measures that may be taken to the advantage of physics and to those who use physics in its application. This led to the appointment of the Advisory Council on Applied Physics of the American Institute of Physics. The Council held a meeting in Pittsburgh in November, 1935 and there adopted certain resolutions, one of which was that the Council have as its aim and function the stimulation of interest for and effectiveness of work in applied physics through the consideration of (a) the education and training of men for work in applied physics, and consultation and exchange of ideas with university faculties in this respect; (b) the services of the Founder Societies and the Institute to physicists engaged in industrial research and other applications, and recommendations concerning programs for meetings, etc., to these organizations; (c) the ways in which the valuable contributions physical science can make, may be brought to the attention of industries not yet well aware of them.

This led, among other things, to the arrangement for a joint meeting of the Founder Societies and the Council in New York last October which was devoted largely to emphasizing coordination of the branches of physics and encouraging their joint application to industrial research.

In the meantime the American Association of Physics Teachers had been requested and accepted the invitation to undertake a study of the training of physicists. One session of the October meeting was under the auspices of the Association and at that time President Webster announced the appointment of the following Committee on the Training of Physicists for the Industries:

H. A. Barton, *American Institute of Physics*
G. A. Campbell, *American Telephone and Telegraph Company*
Harvey N. Davis, *Stevens Institute of Technology*
H. L. Dodge, *University of Oklahoma*
Lee DuBridge, *University of Rochester*
G. R. Harrison, *Massachusetts Institute of Technology*
A. W. Hull, *General Electric Company*
F. G. Keyes, *Massachusetts Institute of Technology*
R. von Nardroff, *Columbia University*
R. A. Patterson, *Rensselaer Polytechnic Institute*
W. Wilson, *Bell Telephone Laboratories*
A. G. Worthing, *University of Pittsburgh*
P. I. Wold, *Chairman, Union College*

In this connection attention should be called to the appointment of a companion committee by the Advisory Council on Applied Physics. This committee under the chairmanship of Paul E. Klopsteg has as one of its functions that of finding what positions at present existing in business and industry should be filled by men who have majored in physics. It is expected that these two committees will work in close cooperation.

The Association Committee has been able to hold two meetings since the October meeting and it is on its behalf that the present report is made.

It is assumed, to begin with, that the interest and efforts of the Association in this matter will be a continuing one over a long period, with such changes in personnel of the committee from time to time as may seem wise. The committee has therefore adopted the policy that while the term "long period" shall not be taken as an excuse for postponing definite actions, it should not feel under pressure of undue haste in its deliberations, with possible detrimental results.

In the discussion that follows it will be taken for granted that *the personality, character, and innate ability of a man are the primary characteristics which determine his success.* It will be assumed that the men who are to be trained possess these prerequisites. The problem of training physicists is not primarily one of making a mediocre man into a first rate man, but rather with providing the able man with more adequate training.

In general, there are three fields for investigation: (a) What positions at present exist in business and industry which should be filled by men who have majored in physics? This, it was agreed, is not within the purview of this committee, but is more appropriately the field of study of the companion committee; (b) What content and what methods in the curriculum will best fit men for these positions? (c) What are the possibilities that an improved program of physics training will open up new opportunities in business and industry which do not now exist?

These major questions must be discussed independently for students pursuing each of the following programs: (1) An arts course with a major in physics; (2) A Bachelor of Science course with a higher concentration in physics than is implied in the usual physics major; this will include courses of study designated as applied or engineering physics; (3) A five-year course in general or applied physics leading to the M.S. degree; (4) A Ph.D. in physics.

It seemed clear that the first task was to study intensively the question of setting up an ideal or model curriculum in applied or engineering physics leading to the B.S. degree; the other problems can then be studied more effectively when this basic one is clearly understood. Hence, after considerable exchange of views, it was agreed that a sub-committee be appointed by the chairman to study the formulation of a "B.S. in physics" course with respect to both content and methods which will best prepare students to enter industry as physicists. This sub-committee will be faced at once with the fact that its educational program must be based upon the training in science and mathematics which our students have received in the secondary schools. It is a serious question whether physicists can be given adequate college training in four years without improvements in their school preparation. The Committee believes that this is a fundamental problem with many difficult aspects underlying the whole field of science education and that it should be given prolonged study by a special group. Accordingly, it was voted that the Association of Physics Teachers be asked to consider the appointment of a special committee to examine the problems of secondary school training in science and mathematics required for admission to college, and to ascertain ways and means by which the Association may assist in the solution of these problems. If such a committee be appointed, our committee will offer its fullest cooperation in any study that may be undertaken.

If it is assumed that the aforesaid sub-committee will confine its attention to undergraduate work, then it is probable that another sub-committee should study the problem of graduate training leading to the M.S. and Ph.D. degrees. Such a study will involve certain questions and difficulties. In the first place, the existing graduate curriculums should be examined critically with a view to determining whether they are best fitted to the needs of men going into industrial work. In doing this, recognition must be given to the fact that the extraordinary advances of physics in this country have been made possible partly because training and research in physics have been allowed to take men into new fields without regard to the practical or industrial applications of these fields. No steps should be taken that would limit this freedom which is essential to the development of physics as a science. Inasmuch as physicists with Ph.D. training will probably be appointed primarily to research positions in industry, it seems essential that they be brought into contact with research problems of present day physics. It is a serious question, therefore, as to whether industries, either for their own good or the good of physics as a whole, should attempt to direct graduate work along the so-called practical lines. It is impossible to predict whether or not the "brilliantly useless" work of today may not lead to the important practical problems of tomorrow. Consideration of this problem is to be deferred until reasonable unanimity has been reached on the preferred requirements of undergraduate training.

P. I. Wold, *Chairman*

Recent Publications and Teaching Aids

Reference Books for the First Course

The Renaissance of Physics. Karl K. Darrow, research physicist, Bell Telephone Laboratories. 310 p., 45 fig., 15×22 cm. *Macmillan*, $3. As one should be able to guess from its authorship, this book for the general reader combines good physics with a charming and distinctive style, a clear exposition and good pedagogic sense, and an unobtrusive revelation of breadth of interests—which is about all that should be needed to arouse the sympathetic attention and respect of the intelligent layman or, for that matter, the first-class physics student. To produce a popular book having such qualities without having to resort to exaggeration, over-simplification, weak analogies, and sentimental claptrap is a difficult task and a real accomplishment. The author is one of very few physicists who are both equipped for the task and able to take it seriously. The chapter titles are: Physics and the physicist, Intimations of electricity, Release of electrons from matter, Magnets and moving charges, The atom visible, Light in the semblance of waves, Mystery of waves and corpuscles, Structure of the atom, Technique of transmutation, Victory over the elements, Unity of nature.

First Year Laboratory Manuals

A Laboratory Course in College Physics. V. E. Eaton, assistant professor of physics, Wesleyan College. 57 p., 43 fig., 21×27 cm. *Edwards Bros.*, lithoprinted. Many of the 26 experiments in this manual possess novel features. Some of them deal with subjects that are not always treated adequately in the textbooks; for example, capillary waves, and standing waves in strings. Experiments leading to numerical results are emphasized, on the ground that students are more interested in them than in experiments that check the validity of long-established laws. Single copies of the manual may be obtained from the author at the cost price of $1.65.

First Year and Intermediate Textbooks

Lessons and Problems in Electricity. Newell C. Page, professor of electricity, Massachusetts Institute of Technology. 370 p., 161 fig., 14×22 cm. *Macmillan*, $2.75. The course in electricity and magnetism provided by this textbook is designed for sophomore engineering students who have had high school physics and the first college courses in mechanics and the calculus. Stress is not placed upon engineering details, however, but upon fundamental principles, including those of particular importance in engineering practice. The book is readable and modern, and characterized by unusual simplicity of presentation; but it is not aimed at students who have to be persuaded to learn. Science majors who have had only a descriptive, persuasive-type of elementary course in electricity should find it exceedingly useful as a review or reference text.

An Advanced Course in General College Physics. Paul Leverne Bayley, associate professor of physics, and Charles Clarence Bidwell, professor of physics, Lehigh University. 355 p., 235 fig., 8 tables, 14×22 cm. *Macmillan*, $3.50. This is the first printed edition of an excellent textbook that appeared originally in lithoprinted form [Am. Phys. Teacher **4**, 46 (1936)]. It is a carefully prepared, rather concise presentation of fundamental general physics which is reenforced by unusually good diagrams and well-selected problems. Although intended primarily for a second course in general physics for engineering and science students who have had an elementary, descriptive course in physics and courses in mathematics up to calculus, the treatment is thorough and complete enough to be used with success as a basic text or reference for any serious beginner who has a good mathematical background. All the usual branches of general physics are covered; namely, mechanics and sound (88 p.), heat (62 p.), electricity and magnetism (95 p.), light (67 p.), electron physics and quantum theory (22 p.).

Elements of Mechanics. Henry A. Erikson, professor of physics, University of Minnesota. Ed. 3. 289 p., 143 fig., 14×20 cm. *McGraw-Hill*, $2.25. This textbook embodies the experience gained from giving for many years a quarter course in the elements of mechanics at the University of Minnesota. The treatment is mainly deductive in character and is extremely concise; in places it is hardly more than an outline, in keeping with the author's belief that "a textbook should carry the student only to that point from which through his own effort he may complete the clarification and attain the desired conception of the physical laws and quantities involved." Trigonometry and college algebra are presupposed. There are many worked examples and these are emphasized by making them an integral part of the text. The unsolved problems, of which there are three complete sets for each chapter, are almost exclusively algebraic, rather than arithmetic, in character. The first third of the text deals with kinematics, including rotation and periodic motion. In the dynamics, one notes that a distinction is made between inertial, gravitational, and "material" mass, the last being defined as the ratio, independent of position and velocity, of the number of neutrons and protons in the body to the number of these particles in the standard body. The last four of the 17 chapters deal with the mechanics of liquids and gases.

At Minnesota this course is followed by quarter courses in elementary sound, heat, electricity, and optics. The textbook for electricity was written by A. Zeleny (ed. 2, 1935), and that for optics, by J. Valesek (ed. 2, 1932). Texts for sound and heat are being prepared by J. W. Buchta and L. F. Miller, respectively.

Mechanics, Molecular Physics, Heat, and Sound. Robert Andrews Millikan, director of the Norman Bridge Laboratory of Physics, California Institute of Technology, Duane Roller, professor of physics, University of Oklahoma, and Earnest Charles Watson, professor of physics, California Institute of Technology. 498 p., 268 fig., 55 pl., 22 tables, 15×23 cm. *Ginn*, $4. This is indeed a splendid textbook. It is "for the serious student who seeks a thorough training in science or engineering, who has already mastered trigonometry, and

who has the equivalent of a good secondary-school course in physics." The serious students of the future will be fortunate in having the book. First and most important, the subject proper is clearly developed in a coherent way. Assumptions are explicitly stated, limits of validity are indicated, approximations are discussed. The customary intellectual gold bricks are not proffered. The experimental foundation and significance of the whole subject are properly stressed. Detailed directions for 32 laboratory experiments are included.

The book is radical in one respect: it seems to have been written for a student who is eager to learn. This tone is given by the wealth of references, the lists of questions, the fully explained typical problems, the answers supplied for the several hundred further problems. It would be excellent for self-instruction. An unusually rich collection of supplementary biographical and historical material adds greatly to the intellectual value. It does tend, however, to impart an antiquarian flavor to the whole; this might have been balanced advantageously by inclusion of additional modern experimental work, especially in the chapters on molecular physics and on wave motion and sound. Let us be truly thankful for this fine book, and hope that the authors will write a companion volume in the other branches of physics.—Louis A. Turner, *Princeton University.*

Upper Division Textbooks and References

An Introduction to the Study of Air Mass Analysis. Jerome Namias and Hurd C. Willett, Massachusetts Institute of Technology. Ed. 3. 86 p., 9 fig., 14 tables, 15×23 cm. *American Meteorological Society* (Milton, Mass.), paper cover, 60 cts. This bulletin supplies the need for an introduction to the important method of air mass analysis. Meteorologists equipped with only an elementary knowledge of mathematics and physics have found the task of approaching the subject through journal articles a difficult one, for there has been no elementary text that deals with many of the fundamental principles involved in the method.

Elements of Nuclear Physics. Franco Rasetti, professor of spectroscopy, Royal University of Rome, and research associate, Columbia University. 341 p., 49 fig., 8 pl., 37 tables, 15×23 cm. *Prentice-Hall,* $4.50. A concise, clearly written survey of the present status of experimental and theoretical investigations of nuclear phenomena. Except in the case of a few topics, extensive theoretical analyses have been avoided, results only being given. The first half of the book deals with radioactivity; the remainder, with general properties of nuclei, theory of nuclear structure, artificial disintegration, and cosmic rays. The references to the literature have been selected with care.

Vibration and Sound. Philip M. Morse, associate professor of physics, Massachusetts Institute of Technology. 366 p., 88 fig., 3 pl., 10 tables, 15×23 cm. *McGraw-Hill,* $4. An up-to-date textbook on the theory of vibrations and sound, designed for students of physics and of communications engineering who have a thorough knowledge of elementary calculus and of the fundamentals of mechanics. Emphasis on older theory is confined to those parts that are still important and in this way room is made in the text for the newer applications and points of view that have come in with the developments of atomic physics, of electronic devices, and of the mathematical technic of the quantum mechanics. Particular attention is given to theoretical methods—to the ways a theoretical physicist attacks a problem and finds its solution; as the author points out, this is a subject that is too often neglected, especially in engineering courses.

History and Biography

Two Hundred Meters Down—The Story of Amateur Radio. Clinton B. DeSota, assistant secretary, American Radio Relay League. 190 p., 16×24 cm. *American Radio Relay League* (West Hartford, Conn.), paper cover, $1. A comprehensive, carefully prepared history of amateur radio. It is Publication No. 13 of *The Radio Amateur's Library.*

Pascal—The Life of Genius. Morris Bishop. 398 p., 12 pl. and fig., 15×24 cm. *Reynal & Hitchcock,* $3.50. Although written in the modern manner and intended to be popular in character, this biography shows regard for accuracy of detail and apparently is the result of a considerable study of source material. Three of the 13 chapters deal with Pascal as an inventor, physicist, and mathematician.

Survey Textbooks

A Survey Course in Physics. Carl F. Eyring, professor of physics, Brigham Young University. 395 p., 224 fig., 15×23 cm. *Prentice-Hall,* $3. Every teacher who is interested in developing a one-semester physics survey or orientation course for non-science students should examine this book. The course which it provides, although intended to be brief, involves good physics and is relatively free from superficiality. This is largely because the author has limited the subject matter by intelligent selection, and has not attempted to skim through the whole field of the usual general course. Enough material is included, however, so that parts may be omitted in adapting the course to groups of students with particular interests. Simple problems and lists of well-chosen, specific references accompany the chapters. The illustrations and format are excellent. The book is one of the "Prentice-Hall Physics Series."

School Textbooks

Unified Physics. Gustav L. Fletcher, James Monroe High School, Irving Mosbacher, Morris High School, and Sidney Lehman, James Monroe High School, New York City. 674 p., 720 fig., 14×20 cm. *Mc-Graw-Hill,* $1.80. The authors have attempted to unify the traditional subdivisions of physics by treating the whole subject as the science of matter in motion. The main emphasis is placed on physical principles, although many practical applications are included for the purpose of arousing interest. Each chapter has a summary which consists of completion sentences.

Science in the World of Work. Frank R. Deming and Joseph T. Nerden, State Trade School, Meriden, Connecticut. **Vol. 1, Applied Mechanics,** 213 p., 177 fig., 14×20 cm, $1.28; **Vol. 2, Applied Physical Science,** 292 p., 144 fig., 14×20 cm, $1.48. *McGraw-Hill.* In these two textbooks for trade schools, the topics are approached through imple-

ments and materials familiar to the students and are developed through extremely simple, qualitative experiments with "home-made" equipment. The authors believe that science training in the secondary school should be limited to qualitative understandings and applications.

Miscellaneous

Frontiers of Science. Carl T. Chase, assistant professor of physics, New York University. 363 p., 19 plates, 14 × 21 cm. *Van Nostrand*, $3.75. The "Science Book Club" recommends this humanized, nontechnical account of achievements in modern astrophysics, physics, chemistry, biochemistry, biophysics, and the science of health. The sections on astrophysics and physics are vivid, convincing, and remarkably understandable, when one considers their brevity and nontechnical character. The remaining sections of the book appear to be less satisfactory. In places the drama becomes tense. For instance, in introducing de Broglie's work: "When it arrived, its dénouement was so sudden that many physicists still find themselves gasping for breath. And the reading public, at least that part interested in the doings of the scientists, has been well-nigh asphyxiated." This may clear up something that most of us have observed with some of the students in physics classes.

Scientific Progress. James Jeans, William Bragg, E. V. Appleton, E. Mellanby, J. B. S. Haldane, Julian Huxley. 212 p., 31 fig., 14×20 cm. *Macmillan*, $2. Contains six lectures for laymen on "Scientific Progress," which formed the general subject of the 1935 Halley Stewart Lectures in England. The titles are: Man and the universe, Progress of physical science, Electricity in the atmosphere, Progress in medical science, Human genetics and human ideals, Science and its relation to social needs.

Wiley Engineering Handbook Series: Vol. I, Engineering Fundamentals, ed. by Ovid W. Eshbach, 1081 p., $4; **Vol. IV. Electric Power,** ed. by Harold Pender, William A. Del Mar, and Knox McIlwain, 1300 p., $6; **Vol. V, Electric Communication and Electronics,** ed. by Harold Pender and Knox McIlwain, 1022 p., $5. 13×21 cm. *Wiley*. Because engineering science and practice have developed to such an extent that existing handbooks are growing beyond practical bounds, the new editions of Wiley's widely used handbooks on engineering are being issued as a series of several volumes. Each volume is replete with tables, diagrams, bibliographies, and textual matter giving useful details, rules and practical information on the subjects at hand. Vol. I, which deals with engineering fundamentals, is of particular interest to the physicist and should be in every physics library. Vols. II and III, which we have not seen, deal with mechanical engineering. Vols. IV and V replace the one-volume *Electrical Engineers' Handbook* (1914, 1922); since they no longer contain material on fundamental science and the other engineering fields, their treatment of electrical topics is much more complete than formerly was possible. Although each handbook was prepared by a staff of specialists, and the results are valuable and highly useful, it is a little unfortunate that representatives of the pure aspects of physics did not have a somewhat larger part, editorially and otherwise, in the undertaking. They could have made contributions of appreciable worth.

The Autobiography of a Scientist. Anon. 191 p., 16×23 cm. *Scientific Pub. Co.* (Princeton, N. J.), $2. The laity is not in the best position to interpret the humor and the exaggerations in these "Memoirs of Doctor Henry Manure, professor at Derbytown University," and those who have passed the graduate level and are teaching in college will have already laughed at most of the things at which the book pokes fun. If you have not read anything of this kind, you may find the book entertaining and mildly amusing.

Charts and Posters

Automobile Wall Charts. *General Motors Co., Research Lab. Sec., Technical Data Dept.* (Detroit), gratis. Four valuable diagrams, free from objectionable advertising:

Automobile Stopping Distance for Different Road Surfaces, 56×86 cm, showing reaction, shortest stopping, average stopping and longest stopping distances for seven different speeds;

Diesel Cycle Diagram, 43×54 cm, for both 4-stroke and 2-stroke cycle engines;

Efficiency of Different Types of Engines, 43×54 cm, illustrating efficiencies of steam, gasoline, and Diesel engines.

From Iron Ore to the Finished Automobile, 56×79 cm, an ingenious diagram of the steps in automobile manufacture.

Motion Picture Films

Steel—A Symphony of Industry. Sound film, 35 mm, 10 min. *American Iron and Steel Institute* (350 Fifth Ave., New York), lent gratis. A theatrical version giving impressions of a basis industry.

Let's Go America! Men and Machines. Sound film, 16 or 35 mm, 10 min. *Motion Talking Picture Service* (250 W. 57th St., New York), lent gratis. A "patriotic screen editorial" narrated by Lowell Thomas and sponsored by the National Association of Manufacturers, on the progress of industrial America and the question of whether the machine will destroy jobs, or create new ones.

Research Paves the Way. Silent, 16 mm, 15 min. *International Nickel Co.* (Distributed by Douglas D. Rothacker, 729 Seventh Ave., New York City), lent gratis. Research and development in the manufacture of nickel alloys. No advertising.

The Story of the Carbon Arc. Sound film or silent, either 16 or 35 mm, 27 min. *National Carbon Co.* (Madison Ave., and W. 117th St., Cleveland, O.), lent gratis. Illustrates the manufacture of carbons and various uses of the carbon arc.

Aces of Action. Sound film, 16 or 35 mm, 67 min. *Minneapolis-Moline Power Implement Co.* (Adv. dept., Minneapolis, Minn.), lent gratis. Use of the tractor on farms and a trip through a tractor factory.

Making of a Modern Newspaper. Sound disk, 35 mm; or silent, 16 mm, 15 min. *Minneapolis Daily Star* (Circulation dept., Minneapolis, Minn.), lent gratis. From reporting to the finished newspaper. Includes scenes of photo-transmission by telephone.

Digest of Periodical Literature

Laboratory and Demonstration Apparatus

A simple apparatus for surface tension measurements. W. E. Haskell; *Chemist-Analyst* **25**, 70–1, July, 1936. An Autostrop safety-razor blade and an analytical balance may be used in place of the wire frame and delicate spring balance ordinarily employed in the direct method of determining the coefficient of surface tension. One pan of the balance is replaced by a wire with a hook at each end. From this is suspended another wire shaped into an inverted V with hooks on the ends to hook into the notches of the carefully cleaned blade. Balance is obtained by attaching a weight of rolled lead to the first wire. With the rider placed on the side from which the blade is suspended so that the pointer is displaced one division mark, the liquid is raised until it makes contact with the blade. Weights are then added until the blade is just pulled loose. The error for water is less than 1 percent.

Science Education

A novel experiment. S. B. Arenson; *Sch. and Soc.* **44**, July 4, 1936. For the past two years the University of Cincinnati has successfully conducted a series of lectures on "The Applications of the Physical Sciences" to which were invited some 700 high school juniors and seniors recommended by their teachers as being among the top 10 percent of their classes in mathematics, physics, and chemistry. The attendance was 400–700. The lectures are illustrated by demonstrations, motion pictures, or slides. They are held on consecutive Saturday mornings. Admission is free, each invited student being supplied with a ticket for the series. The first year it was thought best not to admit the many teachers who asked permission to attend, but the second year the teachers of *all* the sciences in secondary schools within a radius of 25 miles of Cincinnati were invited to "preview" the lectures which the students themselves were to hear and see later in the year. Two different series of lectures have been provided and it is planned to alternate them so that eligible students can attend both series during their last two years of school. The titles and departments of the speakers are:

Series 1. Vibration, waves and sound (phys.), Atomic structures (phys.), Visible and invisible light (phys.), Nitrogen of the air made valuable (chem. eng.), From soft iron ore to hardened steel (metal.), Building of the George Washington Bridge (civil eng.), What makes it fly? (aero.), Some electrical engineering studies (elec. eng.), Geologist's share in the finding of oil (geol.), From Galileo to Einstein (math.).

Series 2. Physics of air in motion (phys.), Clay and clay products (ceramics), On oxidation and combustion (chem.), Diesel engines (mech. eng.), Controlling soil erosion (geol.), Reactions of organisms to radiation (math., zool.).

Questions about this plan should be addressed to the author, Department of Chemical Engineering, University of Cincinnati.

History of Science

The place of science in general history. F. S. M.; *Nature* **138**, 575–6, Oct., 1936. General history until recently has had little or nothing to say about the achievements of science. The emphasis on the governmental side of history has been extreme and must be corrected gradually. To have separate chapters, written by specialists, included in histories is not enough; the need for synthesis in treatment must be met and it must be shown how the scientific spirit has made itself felt in the realms of government, religion and social life. It is most important to enlist the general historians in this cause, for they have the historical spirit and the technic. An alliance between the historians and the scientists and an enlargement of the old historical discipline would be an educational revolution of the most far-reaching type.

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Appointment Service

Representatives of departments or of institutions having vacancies are urged to write to the Editor for additional information concerning the physicists whose announcements appear here or in previous issues. *The existence of a vacancy will not be divulged to anyone without the permission of the institution concerned.*

12. Ph.D. Cornell, B.S. Bowdoin College. Age 38, married. 11 yr. teaching in both men's and women's colleges in East and South. Research in electron physics. Special interest in development of demonstration lectures, laboratory experiments and equipment. Glass blowing.

13. Ph.D. Cornell. Age 31, married, 2 children. 4 yr. college teaching, 5 yr. full-time research in x-rays. Primarily interested in college teaching and research. Hobbies: photography, geology, music.

14. Ph.D. Chicago, B.S. Bradley Polytechnic, with minors in math. and chem. Age 25, married. 4 yr. laboratory and teaching assistant, Chicago. Research, Faraday effect at high frequencies.

15. Ph.D. Iowa State, B.S. in E.E. Minnesota. Age 33, unmarried. 5 yr. sales and research engineer; 4 yr. teaching fellow, physics. Research, effect of gas on metal surfaces used for electron recording, etc. Interested in teaching.

16. Ph.D. Indiana. Age 38, married, 2 children. 6 yr. college teaching. Research in acoustics. Trained for teachers college or university position. Interested in teaching, laboratory development, and research.

17. Man, age 39, married, 1 child, Protestant. Ph.D. Univ. of Pittsburgh. 14 yr. teaching undergraduate physics; 5 yr. asst. prof., important eastern university. Desires professorship in medium sized progressive college; available fall 1937.

18. Ph.D. Penn. State. Age 36, married. 11 yr. college teaching experience. Prepared to teach and interested in developing strong courses in advanced mechanics, heat, electricity, and modern physics as well as elementary physics. Desires assistant professorship where there is an opportunity to progress and develop.

Any member of the American Association of Physics Teachers who is not employed in a capacity that makes use of his training in physics may register for this appointment service and have a "Position Wanted" announcement published without charge.